Voice control and management in smart home system by artificial intelligence

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Abstract. The paper provides a 3D architectural model of Smart Home system. An information data sets of parameters in sound analysis of test voice commands were collected. The following analyzed indicators are included, respectively LZE, LZ eq, LZF, LZS, LZI, LAE, LAeq, LAF, LAS, LAI, LCE, LC eq, LCF, LCS, LCI and LEX8h. Backpropagation and Hybrid algorithms based Artificial intelligence (AI) and Adaptive neuro-fuzzy interface system (ANFIS) were synthesized. Selected architectures are integrated in intelligent automated voice control system for human access control, power switching and lighting, air conditioning systems and home appliances. In the process of synthesis, different criteria for network performance in the analysis of activation type in the output layers in AI and input layer in ANFIS are applied. About all considered voice categories for functional control an accuracy of 100.0% was established. Verification procedures concerning reliability of the achieved results were performed for correct confirmation.

1. Introduction

Modern intelligent vision and speech systems are based on deep neural network architectures and algorithms, among which can be mentioned Convolutional Neural Networks (CNN), Deep generative models (Deep Belief Networks - DBNs), Stacked Auto-Encoders (SAEs), Variational Autoencoders (VAEs), Generative Adversarial Networks (GANs), Flow-Based Models, Recurrent Neural Networks (RNNs) and Long Short-Term Memory (LSTM) networks. Trends show that smart home technologies are gaining ever higher speed given the growing urbanization of the urban environment, resulting in the emergence of new products based on artificial intelligence (AI) [1,2,3]. According to the literature studies, AI integration is associated with five main functions: Device Management, Energy Management, Healthcare, Intelligent Interaction and Security [4,5]. The role of AI is to provide activities such as Data Processing, Voice Recognition, Activity Recognition, Decision Making and Prediction Making [6,7].

The paper shows a conceptual design of a Smart Home type system for building automation with integration of voice analysis and control based on Artificial Intelligence and Adaptive Neuro-fuzzy interface systems [3,4]. The results of research and synthesis of ANN with Levenberg-Marquardt training algorithm and ANFIS architectures, based on extracted sound indicators in the processing of specified sets of voice commands for access control, activation and control of internal systems and appliances are presented.
2. 3D architectural model of Start Home project and concept of voice control systems

Using the capabilities of the 3Ds MAX platform, an architectural three-dimensional model of "Smart Home" was created. 3D views of various aspects of the project are shown in figure 1. Training and selective procedures for selection of neural architectures for control of installations and household appliances through initiated "voice commands" are provided. For each pronounced command, sound analysis procedures are applied on the basis of which the data for a family of 16 indicators are registered, among which: 1) LZE (DB), 2) LZeq (dB), 3) LZF (dB), 4) LZS (dB), 5) LZI (dB), 6) LAE (dBA), 7) LAeq (dBA), 8) LAF (dBA), 9) LAS (dBA), 10) LAI (dBA), 11) LCE (dBC), 12) LCEq (dBC), 13) LCF (dBC), 14) LCS (dBC), 15) LCI (dBC) и 16) LEX8h (dBA).

Figure 1. 3D views of Start Home – (a) south and (b) sides.

The recorded indicators are used as input variables in neuronal training as each voice command is coded with a separate output neuron and a corresponding and discrete code combination. For example, when identifying two commands, the following combinations are used: "1 0" for Command №1 and "0 1" for Command №2.

3. Analysis and synthesis of artificial neural networks for voice control systems

The research is focuses on activities for searching for optimal neural architectures, i.e. networks with an approximately balanced ratio between "maximum accuracy" and "minimum MSE", in a fixed range of variation of the hidden neurons, respectively from 2 to 15. By limiting the number of experimental hidden neurons, the goal is to increase the speed of the neural computational procedures.

3.1. ANN architecture for home access control and electrical power system activation

A neural network for voice commands identification has been created for:

- switching on of the entire home electrical installation;
- establishing of the front door locking mechanism in an inactive state.
Table 1 illustrates the results of the training architectures within the accepted test limits concerning the hidden neurons. Correct voice identification was found at 2, 7, 8, 11 and 15 neural units, which suggests the network selection to be based relative to the change of the root mean square error. Comparing the tabular indications for MSE, the highest error 0.0567 was found at 7 and the lowest 0.0057 at 2 hidden neurons, determining the choice of the considered ANN (figure 2 (a)).

Table 1. Results in synthesis of ANNs for home access control and electrical power system activation.

| Hidden Neurons | Accuracy, % | MSE     |
|----------------|-------------|---------|
| 2              | 100.0       | 0.0057  |
| 3              | 81.8        | 0.0803  |
| 4              | 54.5        | 0.2449  |
| 5              | 100.0       | 0.0103  |
| 6              | 90.9        | 0.0701  |
| 7              | 100.0       | 0.0567  |
| 8              | 100.0       | 0.0063  |
| 9              | 90.9        | 0.2631  |
| 10             | 81.8        | 0.0901  |
| 11             | 100.0       | 0.0228  |
| 12             | 90.9        | 0.0339  |
| 13             | 100.0       | 0.0097  |
| 14             | 81.8        | 0.2136  |
| 15             | 100.0       | 0.0131  |

Figure 2. Architecture (a), MSE (b) and Network errors (c) in ANN for home access control and electrical power system activation.
The training of the specific ANN takes place within 9 epochs for which the best achieved productivity is 0.015111 (figure 2 (b)).

With respect to the moment of the 9th iteration, the gradient and the variable \( \text{Mu} \) are equal to 0.10634 and 1e-05 when zero validation checks are performed. The final variation interval of the network errors is from -0.2000 to +0.2000 – figure 2 (c).

3.2. ANN architecture for lighting and climate control system

In this subsection the results of the set of procedures for voice control of the main and auxiliary lighting, as well as the ventilation air-conditioning modular subsystem for separate rooms of the home are presented, respectively:

- main lighting in the living room and kitchen;
- auxiliary lighting in the bedroom;
- air conditioning system in the living room and kitchen with a medium degree of heating/cooling;
- air conditioning system in the bedroom in a medium degree of heating/cooling;

### Table 2. Results in synthesis of ANNs for lighting and climate control system.

| Hidden Neurons | Accuracy, % | MSE      |
|----------------|-------------|----------|
| 2              | 59.4        | 0.1327   |
| 3              | 65.6        | 0.1209   |
| 4              | 90.6        | 0.0831   |
| 7              | 81.3        | 0.0634   |
| 8              | 100.0       | 0.0237   |
| 9              | 93.8        | 0.0278   |
| 10             | 87.5        | 0.0582   |
| 11             | 93.8        | 0.0482   |
| 12             | 81.3        | 0.0591   |
| 13             | 93.8        | 0.0331   |
| 14             | 87.5        | 0.0643   |
| 15             | 96.9        | 0.0239   |
| 2              | 59.4        | 0.1327   |
| 3              | 65.6        | 0.1209   |

**Figure 3.** Architecture of ANN for lighting and climate control system.

The performance data from table 2 show a change in the accuracy criterion from 59.4% at 2 to 100.0% at 8 intermediate neurons. A variation MSE range from 0.0237 to 0.1327 was registered here, respectively, at 8 and 2 intermediate neurons. According to the analysis, the most suitable neural model regarding the specifics of the task is an ANN with 8 hidden neurons, shown in figure 3.

A relatively higher number of 61 training iterations were observed, with a maximum network performance of 0.10167 obtained within 55 epochs (figure 4 (a)). For the training period, 6 validation checks were performed. Similar error margins were found for the first and fourth groups, while the highest ones were observed in the second base group. In general, the obtained errors fall in the range of about -0.6000 to +0.5000, as shown in figure 4 (b).
3.3. ANFIS architecture for home access control and electrical power system activation

Activities for training of neural-fuzzy architecture according to an algorithm combining the approaches of least squares and error backpropagation have been performed, in connection with voice control of "home unlocking" and "power-up" procedures. The procedures are targeted using a constant integer type output membership functions. In connection with the provided voice commands, a limit on the number of training sound indicators has been introduced to optimize the test ANFIS architecture given in figure 5 (a). Group of indicators 1) LZE (dB), 2) LZeq (dB), 3) LZF (dB), 4) LZS (dB), 5) LZI (dB) was used.

The activities for the synthesis of a neuron-fuzzy classifier consist in monitoring the "Root Mean Square Error (RMSE)" indicator at a different fixed type of membership function of the input variables. A feature of this type of systems is that the parameters of the input membership functions were adjusted automatically during the training, so as to create architecture with maximum efficiency. The selection of the most adequate ANFIS model is based on a minimum indication of the learning error, in this case 0.017443, registered with the "triangular" type of membership function shown in figure 5 (b).

Figure 4. MSE (a) and Network errors (b) in ANN for lighting and climate control system.

Figure 5. Architecture (a) and RMSE in “trimf” input membership function of neuro-fuzzy classifier for home access control and electrical power system activation.
Figure 6. Fuzzy rules (a) and testing of neuro-fuzzy classifier for home access control and electrical power system activation.

Figure 6 (a) is a graphical interpretation of the defined linguistic rules in the study of ANFIS. Complete correctness was found in the identification of user voice commands, defining the used tools as fully applicable in solving such recognition tasks, as confirmed by figure 6 (b).

4. Conclusion
Artificial intelligence finds more and more manifestations not only in the industry, but also in terms of increasing people's living comfort when building homes of a new modern type. The presented research demonstrates the strength of its computational advantages, as well as the possibility of combining with the mathematical apparatus of fuzzy logic, in the development of voice control systems with potential implementation in homes, offices and buildings.

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