THE INTELLIGENT BUILDING EQUIPPED BY THE NEURAL NETWORK CONTROLING THE KNX DEVICES HELPS INCREASE ENERGY EFFICIENCY

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Summary

Modern buildings are becoming more intelligent every day which helps preventing the waste of energy in cases when use of energy is not necessary. The problem of energy efficiency is in the control of power consumption. Controller has to find the balance between comfort of inhabitants and energy costs. Usually this dilemma is solved by hard wired rules that control energy consumption. These rules have to be analyzed and the system has to be set up, which is expensive. Even more expensive is the change of these rules requiring all these procedures to be processed again. All those problems can be solved by an application that uses network of sensors and actuators to analyze the state of building and gathers all the information from history to analyze inhabitants' behavioral patterns. According to behavioral patterns, the system can predict future steps of inhabitants to increase their comfort as well as find the balance between comfort and consumption. Our application Teiresias [16] employs software developed at our faculty called GAME [15] based on data mining and neural networks to find those patterns. The KNX [10] was chosen as a peripherals network for data gathering. The integration of KNX and GAME was a sufficient basis on which we tested scenarios where we have proven the concept of prediction based on gathered history data. We have theoretically proven the ability of Teiresias to predict inhabitants' needs and easily adapt to behavioral pattern changes. Examples of scenarios include control of heating, AC, ventilation, lights, sun blinds, watering, etc.

1 Introduction

A smart home has to be energy efficient as well. However, the energy efficiency is often contrary requirement to the comfort of inhabitants. The task of an intelligent building automation system is to balance the energy efficiency and users comfort.

The energy efficiency can be precisely measured. On the other hand, comfort is very subjective and has to be estimated indirectly from user interaction with the control system.

Our goal is to develop an intelligent and energy efficient building automation system. The first step is to choose the technology and then to build a simulator, allowing us to design, validate and benchmark several different automation strategies.

2 Adaptive controller designed by means of synthetic data

To build an inductive network, training data are needed. We have generated several sample scenarios to evaluate if the network is capable to learn relations between sensors and desired control commands.

ambient light dark	ambient light normal	ambient light bright	bathroom door	hall motion	bathroom motion	!hall light	!bathroom light
1,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
1,0	0,0	0,0	0,0	1,0	0,0	0,0	0,0
1,0	0,0	0,0	0,0	1,0	0,0	1,0	0,0
1,0	0,0	0,0	1,0	1,0	0,0	1,0	0,0
1,0	0,0	0,0	1,0	0,0	1,0	1,0	0,0
1,0	0,0	0,0	1,0	0,0	1,0	1,0	1,0
1,0	0,0	0,0	1,0	1,0	0,0	0,0	1,0
1,0	0,0	0,0	0,0	0,0	1,0	0,0	1,0
1,0	0,0	0,0	0,0	0,0	1,0	0,0	1,0
1,0	0,0	0,0	1,0	0,0	1,0	0,0	1,0
1,0	0,0	0,0	1,0	1,0	0,0	1,0	1,0
1,0	0,0	0,0	1,0	0,0	1,0	1,0	0,0
1,0	0,0	0,0	0,0	1,0	0,0	1,0	0,0
1,0	0,0	0,0	0,0	1,0	0,0	0,0	0,0
1,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0

Fig. 1 A dataset generated to verify capability of inductive networks controlling hall light and bathroom light based on inputs from several neighboring sensors.

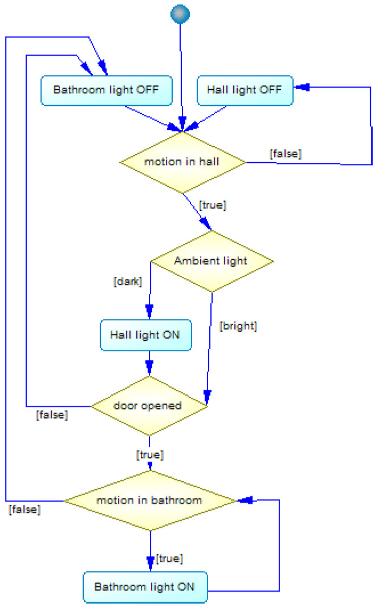

Fig. 2 The state automaton used to generate a data set to evaluate capability of inductive neural networks to control lights in hall.

The data set (**Fig. 1**) was generated using the state automaton in the **Fig. 2**.

In this “hall light” scenario, the neural network was able to learn the control strategy (all testing data was classified correctly).

Furthermore, we used feature ranking algorithm that computed importance of inputs for output prediction (see **Tab. 1**). Results met our expectations. Bathroom light controller is very simple - a single output neuron that copies bathroom motion input.

However in some scenarios, we were unable to construct inductive network with sufficient accuracy. When we analyzed the data, we found conflicting patterns (for identical input signals from sensors, different actions are required). We found that some actions are dependent also on historical state of sensors. In the next experiment, we have solved this problem.

Tab. 1 Table of relevance between inputs/outputs

	ambient light dark	ambient light normal	ambient light bright	bathroom door	hall motion	bathroom motion	bathroom humidity
hall light	19%	8%	19%	10%	33%	8%	0%
bathroom light	0%	0%	0%	0%	0%	100%	0%

3 More realistic adaptive controller with time delayed sensor signals

The “coffee” scenario contained conflicting patterns. Therefore we have enriched the data set by historical states of sensors.

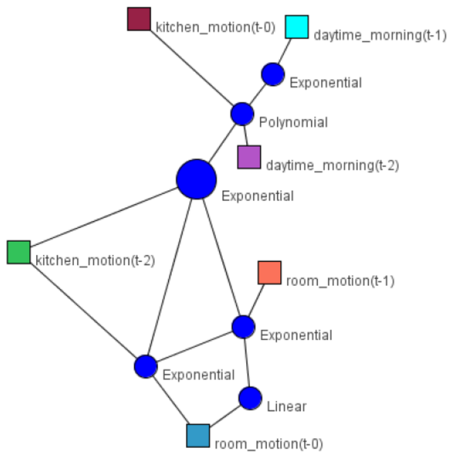

Fig. 3 The output neuron (big circle) controls the coffee heater.

```
coffee = EXP(( -5.780 * (EXP((0.801 *
  room_motion(t-0) - 0.076 *
  kitchen_motion(t-2) - 0.627) *
  20.391) * 0.019 + 0.040) +  1.555 *
  kitchen_motion(t-2) + 0.945 *
  (EXP((0.911 * (EXP((0.801 *
  room_motion(t-0) -  0.076 *
  kitchen_motion(t-2) - 0.627) *
  20.391) * 0.019 + 0.040) -  0.069 *
  (0.348 * room_motion(t-0) + 0.039) +
  0.502 * room_motion(t-1) - 0.401) *
  19.179) * 0.009 - 1.993E-5) + 6.305
  * (14.271 * (EXP((-0.139 *
  daytime_morning(t-1) +  0.013) *
  12.409) * ( - 0.270) + 0.321) *
  (EXP((-0.139 * daytime_morning(t-1)
  + 0.013) * 12.409) * (-0.270) +
  0.321) - 3.777 * daytime_morning(t-
  2) * (EXP((-0.139 *
  daytime_morning(t-1) + 0.013) *
  12.409) * (-0.270) + 0.321) + 0.839
  * kitchen_motion(t-0) * (EXP((-0.139
  * daytime_morning(t-1) + 0.013) *
  12.409) * (-0.270) + 0.321) +
  1.713E-8) - 2.703) * 6.995) * 0.353
  - 9.611E-6
```

Fig. 4 Expression extracted from GAME

The resulting neural network is in the **Fig. 3**. It learned to heat coffee based on actual and historical states of sensors in the neighborhood. The advantage of inductive neural networks is that it can be also written in the form of expressions.

The expression in **Fig. 4** was extracted form the inductive network depicted in the **Fig. 3**. The output neuron (biggest circle) has an exponential transfer function directly connected to time delayed kitchen motion sensor kitchen_motion(t-2).

4 KNX

KNX is the Worldwide STANDARD for Home and Building Control developed and maintained by KNX Association.

In order to transfer control data to all building management components, a system is required that does away with the problems of isolated devices by ensuring that all components communicate via one common language: in short, a system such as the manufacturer and application domains independent KNX Bus.

This standard is based upon more than 15 years of experience on the market, amongst others with predecessor systems to KNX: EIB, EHS and BatiBUS. Via the KNX medium to which all bus devices are connected (twisted pair, radio frequency, power line or IP/Ethernet), they are able to exchange information.

Bus devices can either be sensors or actuators needed for the control of building management equipment such as: lighting, blinds/shutters, security systems, energy management, heating, ventilation and air-conditioning systems, signaling and monitoring systems, interfaces to service and building control systems, remote control, metering, audio/video control, white goods, etc. All these functions can be controlled, monitored and signaled via a uniform system without the need for extra control centers.

Fig. 5 KNX Applications

KNX is approved as an International Standard (ISO/IEC 14543-3) as well as an European Standard (CENELEC EN 50090 and CEN EN 13321-1) and Chinese Standard (GB/Z 20965). KNX is therefore future proof. KNX products made by different manufacturers can be combined – the KNX trademark logo guarantees their inter-working and interoperability. KNX is therefore the world's only open Standard for the control in both commercial and residential buildings.

A benefit in every type of building: From the office complex to the average household. Whatever the kind of building is, KNX opens up complete new opportunities for building control systems while keeping the costs at a manageable level. KNX can provide solutions that can only be realized with considerable effort with conventional installation techniques. Via a single interface, all applications in the home or building can be controlled. From heating, ventilation and access control to the remote control of all household appliances – KNX allows completely new ways to increase comfort, safety and energy savings in the home or building.

4.1 KNX basics

EIBnet/IP allows communications with an KNX/EIB installation by tunnelling over IP networks. The protocol is published in the KNX Handbook [12] and in the European standard EN 13321-2:2006 [13], available from European standardization organizations. Meanwhile EN 13321-2 is useless without information on the KNX/EIB control network specific data structures (cEMI, DPTs); these should be defined in EN 50090 (Home and Building Electronic Systems).

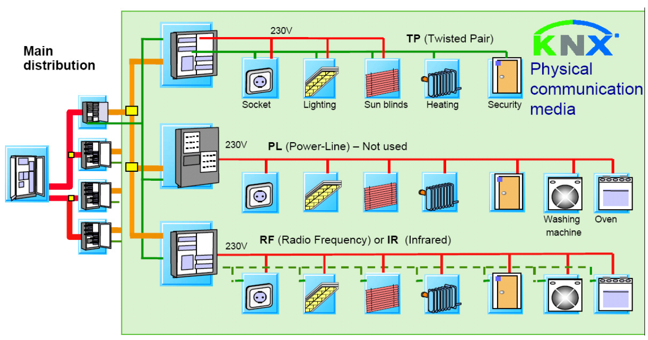

Fig. 6 KNX physical communication media

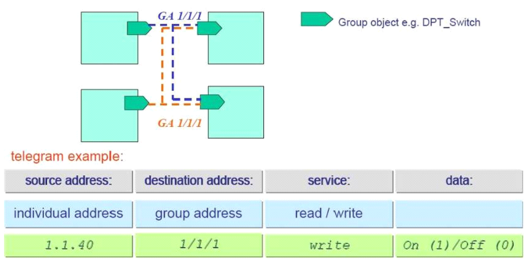

Fig. 7 KNX addressing

KNX protocol is environment independent which illustrate **Fig. 6**. It works on base of Group Addresses. Every device is member of several groups. Sensor sends packet to BUS with set correct group address, every device on BUS read message but only members of same group react on inputs. Others simply discard data. **Fig. 7** shows whole process.

5 Conclusions

We have achieved the goal to partially predict inhabitants' moves and according to them adapt the environment they live in. As a result we could prevent wasting of energy due to improvement in energy efficiency. We could prevent overheating of rooms where nobody was actually staying, turning off electrical devices while nobody was using them, turning on lights in rooms where somebody was moving and off again after he left, watering plants at specific period of day, etc. All these predictions could lower energy consumption and increase money savings meanwhile preserve or even increase the comfort of life.

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