2009-10-01

Beyond Home Automation: Designing More Effective Smart Home Systems

Paolo Carner
Technological University Dublin, paolo.carner@acm.org

Beyond Home Automation: Designing More Effective Smart Home Systems

Paolo Carner
Dublin Institute of Technology,
paolo.carner@acm.org

ABSTRACT

This paper outlines a Smart Home Proof-of-Concept system that uses a Bayesian Network to predict the likelihood of a monitored event to occur. Firstly, this paper will provide an introduction to the concept of a smart home system; then it will outline how Artificial Intelligence concepts can be used to make such systems more effective. Finally, it will detail the implementation of a smart home system, which uses an inference engine to determine the likelihood of a fire. The system prototype has implemented using a LonWorks™ hardware kit and a Netica™ Bayesian Network engine from Norsys.

Keywords: Smart Home, Home Automation, Bayesian Networks, AI.

1. Introduction to Smart Homes

A common definition of "Smart Home" is of an "electronic networking technology to integrate devices and appliances so that the entire home can be monitored and controlled centrally as a single machine" [1]. Another term that describe the same technology is "domotics", which derives from the Latin word *domus*, meaning home, and *informatics*, meaning the study of the processes involved in the collection, categorization, and distribution of data.

A Smart Home system requires the following elements to be present: an intelligent control to gather information and impart instructions, one or more home automation devices to be controlled, and an internal communication network that allows the exchange of messages among the control system and the devices. Furthermore today, increasingly more Smart Home systems connect to external resources and network via Internet.

The intelligent control is usually provided by a form of *control system*, usually implemented with a combination of hardware and software. This control system constantly receives information about the environment via *sensors* located within or in close proximity to the house, which can report information such as temperature, humidity, luminance (luminous intensity), temperature, motion, etc. A Smart Home control system operates the connected devices (e.g. appliances) either directly or via *actuators* and influence the environment in order to maintain settings within a certain range (e.g. temperature or humidity) or to carry out immediate or scheduled user's commands (e.g. activate the intrusion detection system).

The home network will provide a shared communication medium and network protocol for commands and information to be exchanged between the devices and the control system and can use any of the following communication media: Powerline, Busline or Wireless. Powerline systems use the existing electrical lines to transmit the signal, Busline require new cabling (usually twisted pair) to be installed throughout the house, and Wireless take advantage of newer technologies, such as infrared, Wi-Fi, Bluetooth, etc. Communication bridges are available to allow smart home systems to utilize more than one medium or protocol when required.

Modern technology is changing the home by providing an increasingly larger number of appliances that come with embedded computing capabilities. Table 1 provides some examples of areas where Smart Home technologies can be utilized today. Smart Homes of the future will be able to integrate all heating, air conditioning, lighting, home entertainment, and security systems together and, though safety, security, and centralized control are currently the most appealing to users, the result of such integration will open new possibilities and the creation of additional services that do not currently exist [2].

Table 1: Areas of application for Smart Home technologies

AREA	EXAMPLES
Welfare	Remote diagnosis and monitoring of in-house patients
Entertainment	Movies on demand; music download; live shows
Environment	Remote control of lighting, heating, air conditioning systems; remote monitoring of energy usage and optimization of resources via implementation of energy saving schemes
Safety	Immediate/remote alert of problems e.g. gas leaks, fire, water leak, CO_2, etc.
Communication	Phone, video conferences, calendar reminders, communication inside and outside the house Self-diagnosis, requests of assistance and automated operations (e.g. food ordering)

2. Smart Homes and Artificial Intelligence

Few of today's off-the-shelf Smart Home solutions will go much beyond providing basic home automation tasks, such as turning a controlled device on or off [3]. However, it is believed that an effective Smart Home system not only should it carry out automated actions on behalf of the user, but be asked to interpret, understand, and, if possible, anticipate the actions required to complete the user's end goal. Furthermore, an effective Smart Home will need to be able to adapt to a continuously changing environment and cater for several different users at the same time. Due to this, designing a Smart Home system that is powerful, capable of making complex decisions, yet still be intuitive to be used by the average household user is an on-going challenge for designers and developers.

Artificial Intelligence (AI) can provide such systems with reasoning tools that facilitate decision-making in event-condition-action scenarios with uncertain or incomplete knowledge [4] that may be required in the areas reported in Table 1.

Bayesian Networks (BN), also known as *belief networks*, *knowledge maps* or *probabilistic causal* networks [5], provide a method of reasoning using probabilities that have already been applied successfully to problems in medical diagnosis with satisfactory results. Promedas is just one example of an off-the-shelf medical software that employs Bayesian Networks to determine a diagnosis [6].

BN can be effectively employed in a Smart Home system to detect potentially dangerous situations; when fed with the information available at the time provided by the Smart Home sensors, they can return the probability for an event to occur. The control center of a Smart Home can then be programmed to take appropriate actions, such as triggering an alarm or sending a notification should a pre-determined threshold be reached, or a sequence of events unfold according to a predetermined progression.

3. Proof-of-Concept System

The Proof-of-Concept system (POC) illustrated in this section will demonstrate the integration of a Bayesian Network model into a Temperature Control (TC) system, which could be implemented in a Smart Home. The system will simulate the following real-world devices:

Sensors:

- A Temperature Sensor (TS)
- A Motion Sensor (MS)
- A Light Sensor (LS)

Actuators:

- HVAC System
- A Fire Alarm Siren

A LonWorks Mini EVK Evaluation Kit, acquired from Echelon Corp., was used to implement the system. The Kit includes the following components:

- Two evaluation boards (FT3120 and FT3150)
- Two Mini Gizmo I/O boards connected to each evaluation board
- A USB Network Interface (U10) used to connect the computer to the LonWorks network and communicate with the devices

The devices were connected using a Busline (twisted-pair) medium; however, a Powerline version offering the same functionalities is also available.

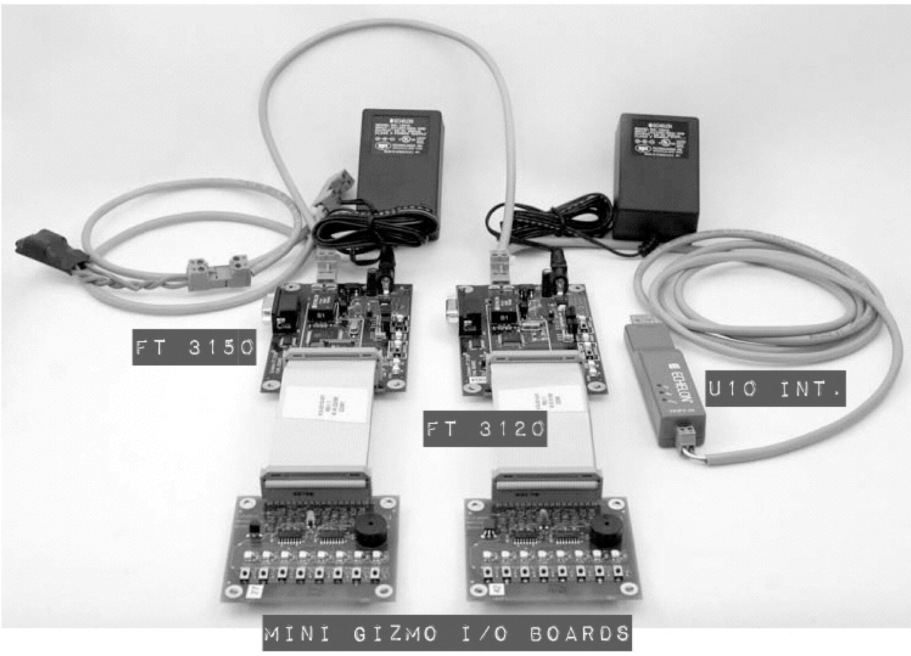

Figure 1 LonWorks Mini Evaluation Kit

Table 2 shows how the real-world devices were mapped in the LonWorks Kit.

Table 2: Device Mapping

Real-world Device	**LonWorks Kit**
Main Switch (entire system ON/OFF)	Switch #1 (ON = activated)
HVAC System	Switch #2 (ON = activated)
Motion Sensor (MS)	Switch #3 (ON = activated)

Real-world Device	LonWorks Kit
Light Sensor (LS)	Switch #4 (ON = daytime)
Temperature Sensor (TS)	Temperature sensor
Fire Alarm Siren	Buzzer

The BN functionality implemented in the POC was provided by the Netica inference engine, by Norsys Software Corp., Vancouver (CA). An evaluation version of the C# Application Programming Interface was downloaded from the Norsys website (http://www.norsys.com/).

The TC is comprised of two main sub-systems: the first one controls the Heating, Ventilating and Air-Conditioning system (HVAC) of the house, while the other is an early-warning Fire Alarm (FA) that triggers when a possible fire is being detected.

Figure 2 displays the main application window: the left pane represents the "control panel", displaying commands, settings and system outputs; while the right pane provides a real-world representation of the system being demonstrated and visual feedback to the user.

Figure 2 Main Application Window

The HVAC sub-system continuously monitored elements such as temperature, the presence of people in the room, and whether it was day or night, and operated the HVAC system as required.

The FA sub-system monitored the environment for a likelihood of a fire and acted as an early-warning system to address potentially dangerous situations. In the POC, the user could set the sensitivity level of the FA operating a slider up or down and set what was deemed to be a high temperature for the particular environment where the FA operates by entering the value in a textbox.

A BN connected to the system provided the real-time probability of a fire event taking into consideration several variables and their influence on a fire scenario. Should the fire probability thresholds reached an alarm (buzzer) would sound. Figure 3 provides the details of the main User Interface for the FA system, with the Sensitivity slider indicating the fire probability threshold, set to 15%, and the high temperature threshold, set to 30°C. The result of the probability calculated by the BN is displayed in real time by the Current Fire Likelihood bar.

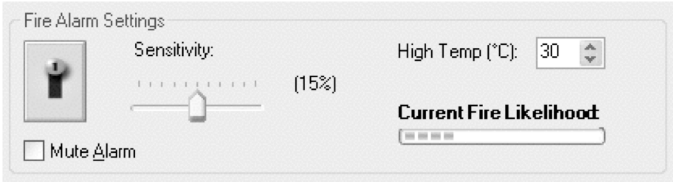

Figure 3 Fire Alarm Sub System

Figure 4 provides a graphical representation of the BN used by the FA, which correlates both events reported by the relevant sensors, the status of other systems, and other relevant environmental variables. The BN continuously calculated the probability of a fire scenario by determining its statistical probability according to state and relationships of the other nodes. Note that the true/false values displayed by the nodes and their relationships indicated in Figure 4 express are not based on any scientific study carried out but represent a hypothetical system that allow to demonstrate the functionality of the POC. The nodes visualized in dark grey ("Lived In", "Daytime" and "Summer") represented ascertained conditions – i.e. based on actual information received by the system – hence the true (or false) probability value was set to 100%. The real-time probability values for the remaining nodes are consequentially calculated based on their relationships with the other nodes.

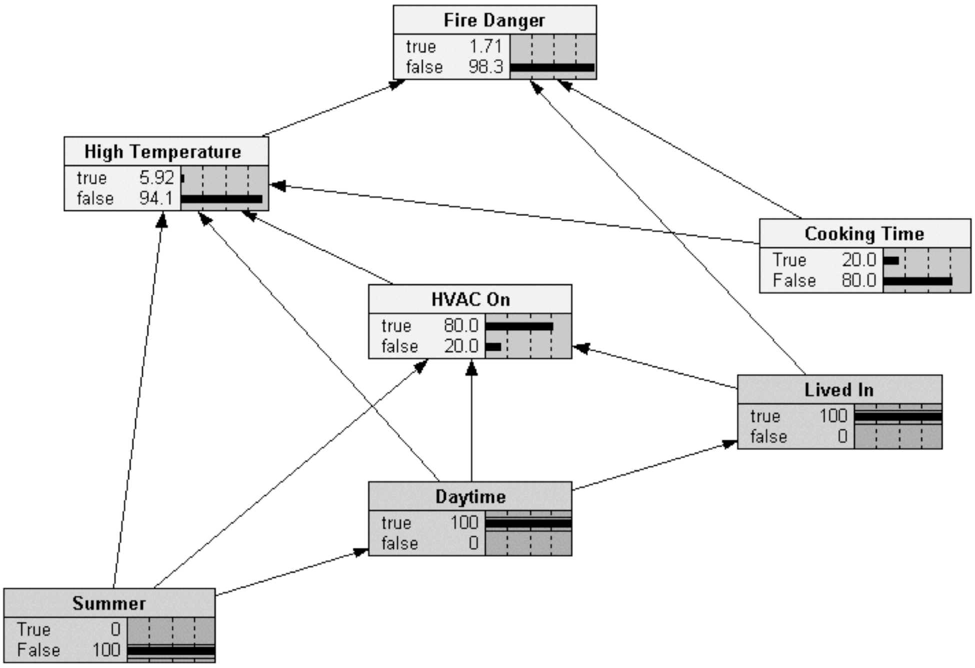

Figure 4 FA Bayesian Network

Table 3 illustrates a possible rationale for the existence of the relationships in the BN. Once again note that the probability values set, the nodes, and their relations in the POC only have the purpose of demonstrating the feasibility of the concept and do not reflect the result of any study carried out on the topic.

Table 3: Bayesian Network Details

Node (values)	**Relationship with**	**Rationale**
Fire Danger (true/false)	*None (root node)*	Fire Danger is the outcome scenario sought by this BN.
Cooking Time (true/false)	• High Temperature • Fire Danger	High Temperature: the temperature might raise above normal values while cooking. Fire Danger: The risk of a fire is somewhat greater when cooking. NOTE: Not implemented by the application. It could be gathered out of evidence such as the oven/cooker being switched on etc.
Daytime (true/false)	• HVAC • High Temperature • Lived In	HVAC: A longer day or shorter night will influence how the HVAC system will operate. High Temperature: Longer summer days are likely warmer; longer winter nights are likely colder. Lived In: The Motion Sensor is likely to be more often ON during the day (people moving around) than at night.
High Temperature (true/false)	• Fire Danger	Causal connection between high temperature in the room and the likelihood of a fire.
HVAC On (true/false)	• High Temperature	It is less likely to have a high temperature when the air conditioning is on (so a high temperature developing in this circumstance might be more suspicious).
Lived In (true/false)	• HVAC On • Fire Danger	HVAC On: This is a direct consequence of the HVAC logic, which is to turn on when the motion sensor is activated. Fire Danger: Here an assumption was made that when there are people in the house there is a minor probability for fire to be developed.
Summer (true/false)	• High temperature • Daytime • HVAC	High Temperature: It is likely to be hotter in summer than winter. Daytime: Days are shorter in winter than in summertime. HVAC: Air conditioning might be turned on more often in summertime (and the heating system in winter time). NOTE: Not implemented in the application. The information might be gathered from a calendar or by other type of evidence.

4. Conclusion

Smart Homes systems ought to move beyond the simple detection of an action towards a truer understanding of the action's significance from the user's point of view. Effective Smart Home systems must go beyond simple home automation, and attempt to reason over the significance of events happening in the house, to be able to provide real added value to the household.

This POC demonstrates that it is indeed possible to make a Smart Home system more effective by integrating AI technologies into it. It provides an example on how a Smart Home system can exchange information gathered from the environment with an inference engine that uses a Bayesian Network to assess the likelihood of an event (e.g. a fire), and how the system can then act based on this assessment. Although the current POC may offer a simplistic view of a Fire Alarm system, it successfully illustrates how such a solution can be implemented in a real-world application.

The concept introduced in this paper can be applied in other areas of Smart Home systems (e.g. Intrusion Alert, Energy Management, etc.) and can be developed further to support different and more complex decision-making scenarios.

Further studies may investigate areas such as how the Inference Engine can adapt its BN as it monitors the user's actions. For example, it could take into account when a user override an automatic action, or consider information coming from the environment in which a Smart Home system operates, such as adjusting default values of the Cooking Time BN node based on when the stove is actually turned on or off by the user. The outcome of such studies will make the system more accurate and increase its effectiveness over time.

5. References

[1] Pragnell, M., Spence L., Moore R. (2000) The market potential for Smart Homes, Joseph Rowntree Foundation, York, UK.

[2] Green, W., Gyi Diane, Kalawasky R., Atkins D., "Capturing user requirements for an integrated home environment", *Proceedings of the third Nordic conference on Human computer interaction*, pp. 255-258, October, 2004.

[3] Carner, P., "Project Domus: Designing Effective Smart Home Systems", School of Computing, BSc. Dublin, Ireland: Dublin Institute of Technology, 2009.

[4] Dimitrov, T., Pauli J., Naroska, E., "A Probabilistic Reasoning Framework for Smart Homes", *Proceedings of the 5th international workshop on Middleware for pervasive and ad-hoc computing*, pp. 1-6, November 2007.

[5] Charniak, E., "Bayesian Networks without Tears", *AI Magazine*, vol. 12, no. 4, pp. 50-63, 1991.

[6] Kappen H. J., Neijt J. P., "Promedas, a probabilistic decision support system for medical diagnosis", Technical Report, F*oundation for Neural Networks (SNN), Nijmegen*, The Netherlands, 2002.