PERSONALISED AMBIENT INTELLIGENCE IN BUILDINGS VIA CONTEXT-AWARE AGENTS

Soi Luong
Technologies for Sustainable Built Environments
University of Reading, Department of Physics, Reading, RG6 6AF, United Kingdom

Samuel Chong
Capgemini U.K.
77-79 Cross Street, Sale, M33 7HG, United Kingdom

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Abstract: One of the concepts of intelligent buildings is to maximise occupant comfort. Optimising the environment for a single occupant is a simple procedure but for a shared environment presents a difficult challenge. This paper proposes the use of context-aware agents that utilises the Hawthorne Effect theory for providing and resolving the conflicting preferences in a multi-tenant building environment. This is an ongoing research and the solution consists of a multi-agent framework for interacting with the environment and learning the occupant's preferences through a user-interface. The agents will learn the occupant's preference using a simple heuristic question and answer method and perception through networked sensors. The Hawthorne Effect solution attempts to resolve the conflicting requirements by fluctuating the heating and lighting during the course of the day to meet all occupants preferences.

1 INTRODUCTION

A typical building has a set of common services such as heating, ventilation and air conditioning (HVAC) systems, lighting, security systems and electrical technologies. All or most of these services are essential to provide a habitable environment that is both comfortable and satisfies occupant needs. The underlying components of these services are sophisticated but can be simply operated by a switch, automated or programmed to run at a certain time of the day.

Large organisations have many offices to accommodate their employees. They are required to provide an ergonomic environment that is compliant with legislation and regulations. It is also of business interest that they configure the internals of their buildings to maximise employee productivity. For example, an office is populated by occupants and computer systems but they must also have bright reflective lighting, central heating systems to keep the occupants warm during the winter periods, air conditioning systems to keep the temperature and humidity levels low during summer periods and ventilation to extract CO_2 from the environment. These services must be fully functional when an occupant is present in the office. However, in a multi-tenant office the services need to be shared and the environment is most likely unable to meet everyone's preferences.

The concept of intelligent buildings was introduced over 20 years ago and its common purpose is to 'maximise occupant comfort' and 'minimise life-cycle cost'. The purpose suggests that we should think about what the occupants want and how intelligent buildings can help an organisation. In the following, we examine the use of context-aware intelligent agents to provide personalised heating and lighting services for human surroundings in a shared office environment.

This is an ongoing piece of research which focuses on examining the agent methodologies which are applicable to maximising occupant comfort. A solution has been proposed and a prototype has been built based on the study of

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related work and current research of intelligent agents and multi agent systems. This paper discusses our contributions to Personalised Ambient Intelligence by presenting a heuristic question & answer interface and the inclusion of the Hawthorne Effect theory.

The paper is presented as follows. In section 2, we discuss the problems associated with this research and construct scenarios for the purpose of validation. Section 3 contains an analysis of the related work by academic research and other pioneering projects. We look at our proposed solution in Section 4. Finally, we critically evaluate and conclude the paper in Section 5.

2 AMBIENT INTELLIGENCE IN BUILDINGS

Raising the topic of ambient intelligence one would certainly envision an array of intelligent devices seamlessly integrated with the environment. The devices know who you are, react to your actions and the environment, and anticipate your desires before you even show it. In reality, ambient intelligence involves ubiquitous computing, user profiling and intelligent systems (Shadbolt, 2003); this denotes the core concept of utilising inexpensive, networked context-aware devices simultaneously with human-computer interaction and behaviour perception for pattern recognition to construct human requirements.

Our approach comprises of three research objectives for designing a system that is ‘seamlessly integrated’ with the devices and the environment.

2.1 Ambient Intelligence

The system should govern the electronic network that is sensitive to occupant’s needs. The problem with existing building services is that when it is required the occupant has to operate it themselves and they may forget to turn if off when they leave the building. Personalisation is required as each tenant has different preferences in which they may want to configure their desired environment. Rather than having the occupant repeatedly informing the system what they want, it should be able to anticipate and change the environment accordingly by continuously recalibrating itself (Shadbolt, 2003).

2.2 Context Awareness

The building services must have the ability to sense and react to the environment through devices, such as, RFID readers for sensing human presence, a thermometer to read the room temperature, etc. But such devices must have a level of sophistication to perceive a situation or human factors: social environment, i.e. co-location of others and group dynamics (Schilit, 2004).

2.3 Intelligent Agent

Intelligent agents are the main focus of the simulation which should be responsible for observing and reacting to provide a dynamic environment through a context-aware interface. Intelligent agents in buildings act autonomously and discreetly from occupants requiring initial training and calibration to accumulate its knowledge base of user profiling to provide personalised services in an office environment.

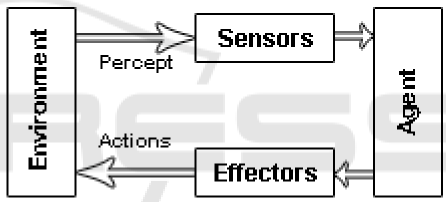


Figure 1: How agent interacts with environment through sensors and effectors.

Intelligent agents are categorised into four classes based on the degree of perceived intelligence and capability:

1. Simple reflex agent
2. Goal-based agent
3. Utility driven agent
4. Learning agent

Simple reflex agent methodology is based on a condition-action rule: if certain criteria meet the condition then it will perform an action. Other complex agents, such as, goal-based and utility driven agents behave in a similar fashion to find possible solutions to achieve its goal. The actions performed are repeated until it produces the desired result or alternatively attempts other methods. Utility driven agents are more selective about which method to undertake and choose the best possible method to achieve a goal (Kozma, 1998). A learning agent has the ability to act independently and learn from past experience. It needs to be able to "adapt its behaviour according to user needs" (Pissinou, 1997). Each agent is able to assess the current state of the environment and perform appropriate actions but a learning agent has the ability to learn from a dynamic context, for example, perceiving the social environment in a multi-tenant office, maintaining a history record of human behaviour and adapting to it to provide a personalised environment.

For this research, we evaluate three scenarios for the purpose of constructing a simulation:

1. User-interaction and personalisation
   Occupants require a method of communicating with the system that manages the building services. Normally, the occupant uses the light switch on the wall to activate the lights, a thermostat to control the heating or an air-condition control panel to provide cool air both of which requires the occupant to enter a value in degree Celsius or Fahrenheit. In order to train a computer, a user-interface is essential to capture the occupant's preferences.

2. Shared services
   In an office environment, HVAC and lighting are shared amongst the occupants. The HVAC operates as a single unit to regulate the room temperature. Lighting is slightly different as there could be several switches for operating lights on separate networks. It would be beneficial if these services could operate independently to provide a personalised service and minimise energy expenditure. For example, the computer system can set the four air conditioning systems in the office to operate at different temperature levels.

3. Social environment
   There are scenarios where all occupants may gather in a room to hold meetings. Prior to entering an assistant to the organiser prepares the room five minutes before the meeting begins to ensure the room is at an acceptable temperature and the lighting is turned on for the attendees. The co-location of the occupants and group dynamics in this situation suggests that the computer must be able to handle a variable context and prepare a personalised service in anticipation.

The scope of this project is to implement a software agent that intelligently manages the heating and lighting of a building office environment. Simulated devices include sensors, radiators, air conditioning and lights.

3 RELATED WORK

Intelligent Buildings is a very broad area of research that comprises of many components which are grouped under four categories: "facilities management, information management, connectivity and overall control" (Flax, 1991). However, this paper focuses on facilities management of heating and lighting in the building.

3.1 Intelligent Agents/Multi-Agent Systems

There are four classes of intelligent agents as discussed in Section 2 and they each act and perform differently from one another. To summarise, the four classes of agents are capable of simply operating by condition-rules, reiterate the best results, be selective about the best results and learn from their environment. The learning agent appears to be suitable for our simulation as one of the main requirements is personalisation.

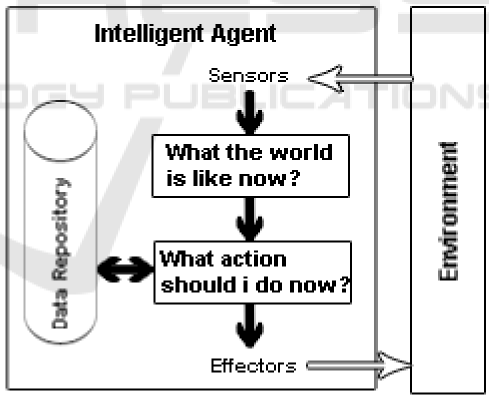


Figure 2: Intelligent Agent Framework.

Typically, this type of agent has a data repository for recording knowledge. But, the definition of *learning* in this scenario would be a domain-specific knowledge base and not an agent that utilises learning techniques, such as, neural networks and genetic algorithms (Chen, 1995). For this project, the intelligent agent keeps a repository of the heating and lighting preferences of each user.

There are many limitations with using a single agent to be the user-interface, negotiator, processor and performer. With the introduction of multi-agent systems, the agents interact and negotiate with each other to solve complex problems which a monolithic system, such as, a single agent cannot do. Multi-agent systems is beneficial in the scenario of not only managing heating and lighting service but user-interaction, sensors, effectors from having their own agent and a negotiation mechanism can be applied between the agents to solve disputes (Mo, 2002).

In a multi-agent system one agent should manage the sensors: constantly observe for the co-location of occupants, anticipate user behaviour, analyse social activity, logging user check-in and check-out time; another agent can focus on energy savings and building controls; and one more agent can manage the interaction between the user to ensure the user preferences are recorded and sent to an agent that is responsible for controlling the services.

3.2 Occupants Comfort

The human comfort zone can be used to describe the occupants' comfort. The optimal body temperature is at 36.8^{o}C (Elert, 2005) and the "occupant's thermal comfort is dependent on the temperature, humidity and air of the room" (Meier, 1994). Some researchers suggest that heating affects the comfort level and productivity of an occupant that is subject to heat stress if comfort zones are not met. Lighting also has an effect on working productivity (Beld, 2001), as the age of the occupant increase their requirement for lighting also increases. The light intensity varies amongst people and occupants accept that having strong light intensity in an office is very important because a lot of creative work is performed and lighting should "guarantee sufficient visual performance for tasks concerned" (Beld, 2001).

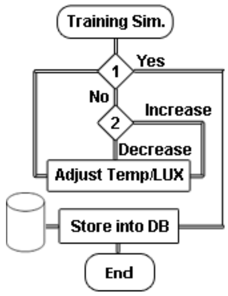
Some of the more recent work like MASBO (Qiao, 2006) uses an approach that balances energy efficiency, occupants' preferences and priority to achieve occupant comfort; Conflict Resolution Architecture is presented by (Lee, 2008) where they try to solve the conflicting requirements of occupants using a "priority" and "privilege-average" approach. ZhengChun Mo (2002) formulated an equation for maximising occupant comfort and minimising electricity costs when one of the agents receives a conflicting request. This sort of conflict resolution is only made possible in a multi-agent system because a single agent would not have enough parameters for negotiating with itself: a single agent will serially perform energy consumption calculations and send commands to the effectors, but it would not raise the issue of whether that command is cost effective.

4 CONTEXT-AWARE AGENTS FOR PERSONALISATION IN INTELLIGENT BUILDINGS

The metrics for identifying temperature is generally Celsius (°C), a common measurement in the United Kingdom, and Fahrenheit (°F). The illuminance of a light bulb is dependent on the energy used and the brightness can be measured by the amount of wattage it consumes. Another metric used to measure the light emittance is LUX. But, in an office environment, do the occupants know how bright their lighting is in LUX? Obviously, they know what temperature the room is at because of a thermostat or a thermometer but does it display the actual temperature: different room dimensions have different temperature readings which also depend on where the thermometer or thermostat is placed. Overall, the occupants are concerned about whether all the lights are working and are very bright, one might find the lights too bright but will have to compromise because they cannot change it, and that if the temperature is not comfortable then they will either continuously adjust the thermostat until they get the desired result or use the air-conditioning.

4.1 User-Interface

The user-interface is designed with a user-centred approach to minimise user intervention and also taking into consideration the usability of the system that the occupants are going to 'train' and calibrate via heuristic question and answer methodology. An expert system called MYCIN utilised this methodology to solve medical problems: a series of closed-questions were used to identify illnesses (Buchanan, 1984). Heuristic question and answer can be used as the training simulation to question the user if they are satisfied with the temperature or lighting and to fine tune the services until the user gets their desired results.



1: Is occupant satisfied with temperature/lighting?
2: Increase or decrease the temperature/lighting?

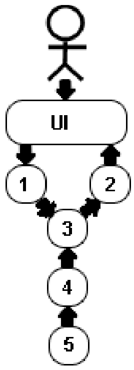
Figure 3: Training Simulation Data Flow Diagram.

The intelligent agent can then learn the occupant's preferences by recording the results of the training. This eliminates the purpose of displaying the Celsius/Fahrenheit and LUX values because the user can assess and feel the environment changes in real-time therefore keeping the user-interface as simple as possible.

4.2 Multi-Agent System & Hawthorne Effect

An office environment has many heaters, air-conditioning and lights. These services can be segregated into zones where each zone will have a certain number of occupants. Each zone has a set of agents for handling the interaction and communication with its occupants via a user-interface, sensors to perceive human actions and co-locations, and managing services within that zone. The multi-agent system makes up a network of intelligent agents that is used for the intelligent building architecture.

UI: User-Interface
1: User Agent



2: Effector
3: Local Agent

4: Sensor Agent
5: Environment

Figure 4: Multi-Agent Framework.

The diagram above shows our multi-agent framework design for the simulation. As the sensors and effectors are simulated these has been included in the User Agent and Effector component, as shown in the diagram in which they communicate with the User-Interface.

To tackle the problems of sharing services between occupants as well as trying to maximise occupant worker productivity the Hawthorne Effect suggests varying the environment so that it meets all the occupants' needs (Draper, 2008). The intelligent agents will not only calculate the occupant's desired temperature and lighting but can also adjust them both accordingly at consistent intervals. For example, if one occupant's preferred temperature is at 24°C and another occupant has a preferred temperature of 24.5°C then the intelligent agent adjusts the temperature to fluctuate between 24°C and 24.5°C so that both occupants are satisfied at several durations within each hour.

The Hawthorne Effect has been criticised by the Maslow's Hierarchy of Needs which states that increase productivity is dependent on the individual's temperament and their need for self-actualisation as well as job satisfaction rather than the environment they are in (Maslow, 1943). Other criticisms have been referenced by Olson (2004) as well as the research outcome of the Hawthorne Effect concluded that worker productivity was temporarily higher because the workers were motivated by the attention and being observed by the research team. However, the intelligent agent in this simulation that utilises the Hawthorne Effect theory is trying to provide the best possible work environment for its occupants and to satisfy their requirements. The agent must also understand that there could be a possibility of having a large gap between the two occupants' preferences which might result in dramatic changes in their environment and that should be avoided by calculating an intermediate result that will benefit both occupants. For example, if the preferences were 24°C and 26°C then the agent should use intermediate values of 24.5°C and 25.5°C to reduce the dramatic effects of having significantly different temperatures. Although, this method may increase energy usage as to compare with using the average value of constant 25°C the intelligent agent's priority is for human comfort.

4.3 Simulation Design

The main focus of the simulation is how the agents respond to the environment but to do this another part of the system should simulate the environment itself. Figure 5 illustrates the environment and external variables as required to help make the simulation as realistic as possible.

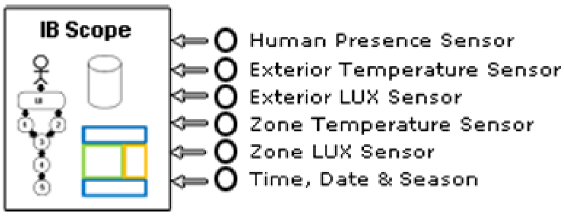


Figure 5: Simulation Design.

The variables external to the scope are simulated values to stimulate the intelligent agents. These will be implemented as part of the system.

5 CRITICAL DISCUSSIONS & FUTURE WORK

A simulation was developed to test the three scenarios stated in Section 1. As this is an on-going research project we can make initial evaluations using test cases of the expected outcome.

5.1 User-Interface

The main objective of the user-interface is simplicity in communicating with the agent which supports the concept of "seamless integration" of intelligent devices. The user-interface is designed as simple as possible but transmits enough information to the agent containing adequate intelligence for perception and anticipation. The user-interface has been designed to show the temperature and lighting measurements to the occupants but this could cause some implications because some users may know what temperature settings they prefer and not relying on the agent to perceive the occupants' feelings for a better judgement.

5.2 Training the Agent

The system allows the user to 'train' the agent and make it understand the occupant's preference. The training uses a set of closed question, for example, "Are you satisfied with the temperature/lighting? Yes/No". If the user selects "No" then it proceeds to ask "What would you like to do with the temperature/lighting? Increase/Decrease". If the user is satisfied then the system records the user's preferences. However, realistically the environment is unable to adjust immediately within seconds and therefore this training process could take a very long time causing a placebo effect with the occupant thinking that the environment has adjusted to their preferences, temporarily. Another problem raised here is the decision making logic of both temperature and lighting is very simple. Probable solution could be to use a binary algorithm to produce better results for the learning agent.

5.3 Hawthorne Effect

In this simulation, the office environment is segregated into zones. For example, Zone A has two occupants with different temperature and lighting preferences. Occupant A prefers the room temperature to be at 23°C, 500LUX and Occupant B would like the room temperature to be 25°C, 525LUX. The agent should fluctuate the temperature and lighting between the two occupants preferences at a very slow rate, i.e. cycle between these preferences twice per hour. This method may maximise user satisfaction but there are two potential issues: changing the temperature is likely to result in an increase in energy consumption and altering the levels of light throughout the day may cause more issues for occupants. But, as with other methodologies (Chen, 1995; Meier, 1994; Buchanan, 1984) these resolves conflicts through compromise but at least the solution here ensures that each occupant is satisfied for various moments throughout the day.

A fourth test case scenario was prepared but the simulation did not support it. The fourth scenario was to simulate how the agent interacts with the environment when it senses that all the occupants have entered the meeting room. From its historical data the agent knows a meeting is scheduled ten minutes prior to the meeting that was held regularly on the same day and time. However, due to the complexity and lack of development time this part of the system was not fully implemented. It should show how the agent tries to cater for all occupants by calculating the average preference and fluctuating from that measurement. It should also continue to monitor who is actually present in the meeting room and adapt the temperature and lighting to users' preferences.

In conclusion, the results of this research project could be criticised for a number of issues. In hindsight, it could be argued that the use of a qualitative research methodology would have been useful in gaining a better understanding of the users' preferences in terms of the management of heating and lighting. The project had assumed that the Hawthorne Effect is preferable with little backing from building occupants.

The heuristic training method could also be criticised for its accuracy and its assessment of the environment. For example, if two users are in the same room and require a very similar temperature, they may not be able to tell the difference between the system's behaviour in fluctuating between the two selected heat settings. As a result, it would not be possible to verify whether the Hawthorne Effect theory is preferred by the occupants to an alternative e.g. keeping the temperature to an average of the two users' preferences. External factors, such as the user's activity within the environment could also be taken into account i.e. depending on a user's level of physical activity; the judgment of the environment's heat level could be misjudged and therefore have a negative impact on the user's perception of the system and the heuristic training method.

There are several improvements or further research that could be made, as listed below:

- The user agent could benefit from a new learning algorithm. Possibilities of using a binary search algorithm to locate a particular value when training the heating or lighting.
- A dedicated agent that is solely responsible for maintaining performance and efficiency of energy usage.
- Improving energy efficiency as this was not included as one of the objectives in this paper. The agents should take into account the internal and external ambient environment and adjust lighting and heating usage efficiently whilst maintaining a comfortable environment. It is expected that the proposed solution could benefit greatly from this, for example, if the outdoor air temperature is cooler than inside the office then we can use natural ventilation to dilute the outdoor cold air with the indoor warm air. Going green and being sustainable is currently a major topic. Research into agent technology could be of great benefit to implementing sustainable buildings for the future.

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