

# Optimizing Heating System Management Using An Activity-Based Pervasive Application

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**ABSTRACT:** *The greenhouse gas effect has become a major preoccupation worldwide. Heating of buildings and houses is one of the major sources of this effect. We propose to optimize heating control systems by directly integrating the recognition of people's activities and context in the process of temperature regulation. We introduce the concept of kinetic-awareness as a way of making a heating control system aware of a user's motion in physical space in order to adjust temperature according to their current activities.*

## Categories and Subject Descriptors

**H.5.1 [Multimedia Information Systems];** Artificial, Augmented, and Virtual Realities; **H.4 [Information Systems Applications] ;**  
**I.2.8 [Artificial Intelligence];** Problem Solving, Control Methods, and Search

**General Terms:** Pervasive Computing, Smart Home, High performance automation systems, User interface

**Keywords:** Context awareness, Heat control systems, Heating system management

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## 1. Introduction

For many years now scientific communities, ecological movements and politicians have been debating about the dramatic impact of human activities on the climate and global warming caused by the greenhouse gas (GHG) effect. Recent scientific proof has awakened the consciences of all classes of people (deciders, workers, families, industries, governments) about an urgent problem that might be catastrophic in the future. The "Kyoto protocol" [1] was defined to foster the involvement of countries in the process of greenhouse gas (GHG) reduction.

The problem we address in this paper is how to reduce GHGs through the smart use of pervasive computing technology. For this purpose we propose a heating system optimization method based on the tracking of people's motion/activity within a building.

### 1.1 Environmental consideration

Today, the GHG effect is one of the main global environmental concerns. Scientists and environmentalists have identified many sources of greenhouse gases [1, 2] and the United Nations have established an inventory of practical rules to reduce them [1, 3]. In the northern hemisphere heating is an important part of life and we rely on its use for about 7 months a year. Buildings

and houses are heated by fossil fuels, coal and natural gases, which are typically sources of GHGs. We take the Swiss case, based on statistics released in 2007 by the Swiss Federal Office of Statistics [4], as an example. The total Swiss population is about 7.5 million people. According to the statistics [4, p. 12], 83% of the total energy consumed in 2005 was non renewable (fossil fuel or nuclear), of which 22% of the GHGs were produced by home activities and 21% by industry. In homes, a significant portion of GHGs are produced by the heating system. For industries, we can reasonably consider that fewer GHGs are produced by the heating system. Heating oil, natural gas and coal are the most used types of fuel in Switzerland (and practically worldwide) and represent about 2/3 of the total energy produced per year in this country. Figures for western European countries<sup>1</sup> for 2002 [4, p.35] show a production of 10.94 tons of GHG per capita per year. These figures highlight the size of the problem just on a limited European scale. If we consider similar figures for all 27 countries of the EU plus North America (USA and Canada) the impact on the environment should not be underestimated<sup>2</sup>.

Based on these compelling motivations, the main issue we would like to address here is "how pervasive computing systems can help reduce GHGs produced by heating systems". We have identified two approaches that could help to reduce the need for heating in inhabited buildings: 1) building insulation (reduce loss of heat) and 2) optimizing the heating system management (heat only when needed). Here we will explore the second approach and propose viable solutions for heating management based on available pervasive computing technology.

### 1.2 Outline of the paper

Thus far we have given the motivation behind our work. In the second section we discuss some related work on Smart Home concepts and projects and the role that a person's activity can play in energy consumption. The third section introduces the concept of a Kinetic User Interface (KUI), while the fourth section proposes an activity-based model for situation awareness. The fifth section describes the uMove API, developed in the Department of Informatics at the University of Fribourg, which serves to develop KUI-enabled applications. Section six describes the Hestia heating system optimiser and conclusions and future work are discussed in the last section.

<sup>1</sup>France, Germany, Italy, Austria, Belgium, Netherland.

<sup>2</sup>In this paper, we did not consider other parts of the world for which we might expect a dramatic impact on energy consumption such as China and India, and for which there is little data available

## 2. Smart Heating Systems

The term Smart Heating System introduces the notion of intelligence brought into traditional heating systems. Intelligence can range from a simple thermostatic regulation to a Web-based management application. We associate a Smart Heating System with the concept of “Smart Home”. It is a part of the intelligence introduced in home environments.

### 2.1 Related work on Smart Homes

“Smart home” technology has become familiar during the last two decades. Smart homes are specific types of “smart environments” defined by Cook and Das [5] as “a small world where all kinds of smart devices are continuously working to make inhabitants’ lives more comfortable”. Several research projects have been carried out and some companies already propose solutions to equip houses with electronic devices and software that control elements such as the lighting system, the security system, the air conditioning and the heating.

The following projects were not specifically designed for heating systems but are cases where users are taken into consideration in the management of their environment. The Smart Home project at Duke University proposes a sophisticated approach to house management including day lighting, a geothermal pump, fire safety and media-on-demand. Another related project is the AwareHome project at GeorgiaTech<sup>4</sup>, but it does not address the energy saving issue.

Looking at the Intelligent Building Management Systems (IBMS), Command & Control Centres (CCC) and Heating, Ventilation and Air Conditioning (HVAC) systems available on the market such as the SSComp<sup>5</sup>, Control4<sup>6</sup>, HAI<sup>7</sup>, and Aprilaire<sup>8</sup>, we notice that most are capable of controlling the temperature only by means of standard thermostats, and focus more on the interfaces used to control them. Basically, when a fixed temperature threshold is passed, this event starts or stops some heating/cooling engine. Although it is possible in some cases to assign different temperatures to different times of the day, this type of control does not adapt to more complex activity patterns and different contexts (e.g. place, time of day, external temperature, etc.). The Aprilaire Zoned Comfort Control system<sup>9</sup> allows users to assign different temperature needs in designated areas of the house, but still retains the threshold model of the thermostat.

Recent advances in ignition technology, such as high-efficiency gas furnaces using electronic ignition, will provide suitable technology for starting and stopping heating systems without keeping a pilot flame lit for the furnace, boiler or water heater to function, because electronic ignition only requires a flame when there is a need for heat<sup>10</sup>.

Some other systems are capable of detecting the presence of people and reacting accordingly, such as Telkonet Intelligent Energy Management<sup>11</sup>, but the user still needs to conscientiously and physically interact with the system by setting their temperature preferences.

<sup>3</sup><http://www.smarthome.duke.edu/program/projects.php>

<sup>4</sup><http://awarehome.imtc.gatech.edu/>

<sup>5</sup><http://www.sscomp.com/shome.htm>

<sup>6</sup><http://www.control4.com/products/components/climate.htm>

<sup>7</sup><http://www.homeauto.com/Products/Omnistat/EnergyManagement.asp>

<sup>8</sup><http://www.aprilaire.com/>

<sup>9</sup><http://www.aprilaire.com/index.php?znfAction=ProductsCat&category=zoned>

<sup>10</sup><http://high-performance-hvac.com/gas-furnaces/hvac-heating/gas-furnaces/electronic-ignition-gas-furnaces/menu-id-69.html>

<sup>11</sup><http://www.telkonet.com/tse/home.html>

Mozer's Adaptive House<sup>12</sup> is an experimental personal research project in Boulder, Colorado and it is as far as we know the only system that observes and learns people's occupancy (i.e. at home or away), preferences (e.g. the room's ideal temperature) and usage patterns (e.g. turn on/off, change thermostat levels), and tries to continuously adjust the temperature accordingly [6]. Basically, the Adaptive House uses people's schedules, preferences and occupancy to save energy by anticipating inhabitant needs. The MavHome project [7] focused on predicting user's behaviour about making decisions about controlling the house's appliances by means of machine learning algorithms, but without any particular emphasis on its application to energy management or heating adaptation.

No other research efforts have been carried out so far to adjust the temperature according to the detected activity of people and the context in which the activity takes place. In contrast, some guides provided by governmental institutions, such as Australia's guide to environmentally sustainable homes<sup>13</sup>, recommend adapting heating and cooling systems to people's activities:

- “Control heaters and air conditioners so they are only used when and where they are needed and are used to achieve a desired temperature”;
- “Analyze your heating/cooling needs and how you will manage these. Ask yourself what rooms need to be heated/cooled, when and to what temperature? Aim to heat/cool living areas when people are home but heat/cool bedrooms only at night and the early morning when they occupied. Bedrooms do not need to be made as warm or as cool as living areas, to be comfortable for sleeping. Avoid heating and cooling halls, laundries etc.”

The European Union, with its Energy Performance in Buildings Directive<sup>14</sup> invites people to “promote the improvement of energy performance of buildings within the community taking into account outdoor climatic and local conditions, as well as indoor climate requirements and cost effectiveness.”

Furthermore, a set of requirements for High-Performance Building Automation Systems with respect to HVAC<sup>15</sup> points out that: “based on zone demand the set point for various heating and cooling sources will change according to demand from the zones”.

### 2.2 Research focus

Analyzing heating/cooling needs and adjusting temperature accordingly is the main focus of our research. In particular, how this can be done 1) automatically and in real-time and 2) in an unobtrusive manner so that the user can benefit from a comfortable environment without having to deal with sophisticated control settings. To achieve this, we explored various possibilities of tracking a user's activities in different home spaces. Specific motion patterns taking place in selected places (e.g. rooms or parts of rooms) denote activities for which we could easily map heating/cooling needs. By combining motion sensors with temperature sensors (both environmental and body sensors) we can build sophisticated heating/cooling control systems that 1) optimize energy consumption and 2) provide the most comfortable temperature to users. Existing heating system management solutions provide different possibilities for temperature settings (including presence

<sup>12</sup><http://www.cs.colorado.edu/~mozer/house/>

<sup>13</sup><http://www.yourhome.gov.au/technical/fs610.html>

<sup>14</sup>[http://ec.europa.eu/energy/demand/legislation/buildings\\_en.htm](http://ec.europa.eu/energy/demand/legislation/buildings_en.htm)

<sup>15</sup><http://high-performance-hvac.com/bas-and-ddc-technical/energy-efficiency/building-automation-systems/building-automation-systems-bas-ddc-hvac-controls/menu-id-90.html>

detection) but, to our knowledge, none of them really take the user's activity into consideration in their algorithms.

### 2.3 Role of the user's activities in heating/cooling regulation

We have all noticed that the impression of the temperature inside a room depends on several factors. The first factor, and probably the most obvious one, is the "bare" temperature of the room. Generally, a living room with a temperature below or equal to 18°C is perceived as "fresh" or "cold" by most people. In contrast, if the temperature is over 24°C, it is often considered as "warm" and people have a tendency to wear lighter clothes. The second factor, more interesting to us, is the user's activity. The impression of the temperature strongly depends on the type of activity the user is carrying out. If a person is physically active in a kitchen (e.g. cooking or cleaning) or in a living room (e.g. cleaning or playing) we estimate that the temperature of the room can be reduced by 1 or 2°C, allowing the body heat to be absorbed by the cooled environment and making people feel more comfortable. Instead, the general tendency of active people in such situations is, in the best case, to manually reduce or cut the source of heat and, in the worst and unfortunately the most frequent one, to simply open a window or a door to quickly release the energy directly into the open air, leaving the heating level unchanged. Still worse, if present, the thermostatic heating control system will react by restarting the heating system because of the drop in temperature, thus causing additional consumption. We estimate that such behaviour increases normal consumption by 15% because of the need to re-establish the original temperature after a drop of 2°C<sup>16</sup>.

On the other hand, if in the same living room people are quietly reading or watching television they will need more heat to feel comfortable. In this case, there are two possibilities, 1) wear something warmer and/or 2) increase the room temperature. The first option is often chosen but users tend to also increase the thermostat to the maximum setting, thinking that the increase will be faster. This operation will end with uncomfortable heat and lead to the remedy of switching the heating off (when possible) or opening the window to let in cold air.

The question is, how can this "energy-wasting" behaviour be avoided? We believe that prediction and continuous regulation are the key. A trained smart heating system will predict that the users will feel warm or cold considering both the current situation and the activity that they are carrying out. In the best case, temperature adjustments are made before the observed activity (based on patterns, for instance) and in the worst case during the activity. If the expected activity occurs, then the system will keep adjusting the temperature to the optimal level. Otherwise, the system can stop before becoming too wasteful.

Another example where temperature and activity are linked is when people sleep. During sleep physical activity is reduced and lowering the temperature in the room has been recommended in order to sleep well. For this case, the system can be programmed to start lowering the temperature after the events of entering the bedroom, turning the lights off and making nearly no movements.

Rooms do not always host the same activities at different times of the day. For instance, a teenager's room is generally a "multi-activity room" where one can find a bed, a desk to study, a place to relax (e.g. to read, to listen to music). In such a case, we can imagine a heating system that will adapt the temperature according to the type of current activity, up to the extreme case where nobody is in the room and the system adapts the

temperature by lowering it to its minimum. Intuitively, our heating system optimiser should be aware of 1) where the people are, 2) what they are doing and 3) predict future activity in order to adjust the temperature before the activity takes place (e.g. start lowering the bedroom temperature one hour before the time people typically go to bed).

It is also important to note that in cases where people are not comfortable with the temperature, how they react to the unpleasant situation is a major cause of energy waste. People tend to manually adjust the temperature by just changing the thermostat setting, unaware that this change has nearly no effect on the speed at which the temperature increases or decreases. They expect the temperature to rise or fall faster or even immediately the more they increase or decrease the thermostat. This is due to the inaccuracy of their mental model of the thermostat system [8]. While an audio amplifier provides direct feedback on the variation of the control, this is not the case for the thermostat, where the control button only sets the highest temperature that has to be reached before the heater is turned off. Often, when users realize that their actions on the thermostat control do not immediately provide the expected result, they try some other energy-wasting actions such as adding an additional heater, or trying to cool down the room by opening the windows. We aim to reduce this erroneous behaviour by making heating/cooling systems more intelligent. This is achieved by making these systems more aware of the user's temperature needs and by predicting them in due time in order to avoid uncomfortable situations as often as possible.

These intuitive analyses led us to the conclusion that it is useful to take into account the user's activity and context (time, environment, actual temperature) to continuously and intelligently adapt the level of heating/cooling in a room. Sensors such as infrared detectors, indoor position detectors and accelerometers provide useful information to the temperature control. This functionality is added to existing control systems which already take care of adjusting the temperature in a remote, automatic or programmed manner.

System management combining recognition of a user's location, motion and activity will henceforth be referred to as a *kinetic-aware system*. We propose to integrate kinetic awareness into heating system management by using the Kinetic User Interface (KUI) model and uMove API [9, 20] developed at the University of Fribourg. The uMove API (Figure 1) is based on the recognition of a user's activity and situations from various properties of motion in physical space.

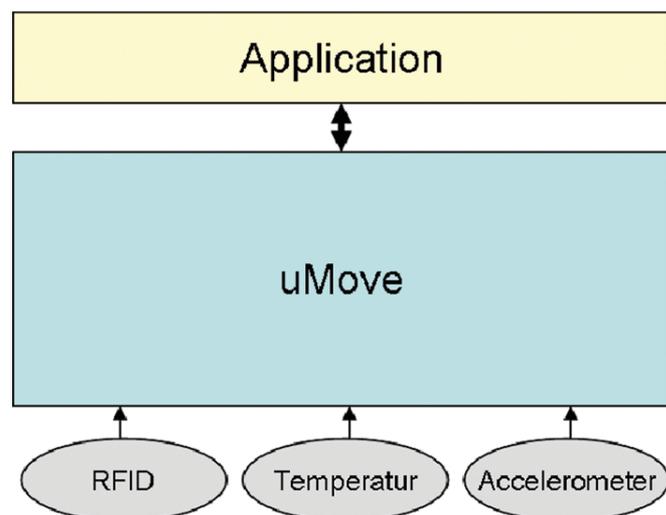


Figure 1. uMove general architecture

<sup>16</sup>Calculations based on data from [http://www.ademe.fr/bretagne/actions\\_phares/energie\\_maitrise/conseils\\_chauffage.asp](http://www.ademe.fr/bretagne/actions_phares/energie_maitrise/conseils_chauffage.asp)

### 3. Kinetic User Interface: a systemic approach

The concept of the Kinetic User Interface [21] is a way to combine Weiser's Ubiquitous Computing vision [10] and Dourish's Embodied Interaction vision [11]. In the early '90s, Marc Weiser predicted that computers would disappear and computing power would fade inside the network infrastructure. Paul Dourish investigated how to move the interface "off the screen" and into the real world. In his model, users can interact with physical objects which have become augmented with computational abilities. The KUI model is a conceptual framework helping in the design of pervasive systems including mobile applications or server-based systems where the motions of users or objects in physical space are recognised and processed as meaningful events.

The KUI model is based on General System Theory (GST). We consider that any user or object moving in their environment is part of a system made up of different components such as buildings, rooms, streets, objects and other users.

For Alain Bouvier ([12], p.18), a system (a complex organised unit) is a set of elements in dynamic interaction, organised to reach a certain goal and differentiated within its environment. It has an identity and represents a "finalised whole". General System Theory (GST) defined by von Bertalanffy [13] gives the framework and the concepts to model specific systems studied in sciences such as biology or chemistry. There exist different types of systems such as inert or dead, living or evolutionary, open (exchanging matter with its environment) or closed. Systems can be made of sub-systems, for instance the earth being an extremely complex living system and also being one component of the solar system (holistic concept). Boulding, in [14], writes: an "individual" - atom, molecule, animal, man, crystal - (entity) interact with its environment in almost all disciplines. Each of these individuals exhibits "behaviour", action or change and this behaviour is considered to be related in some way to the environment of the individual, that is, with other individuals with which it comes into contact or into some relationship. The important points in Boulding's definition are that 1) the entity's actions (activities, behaviour) are related to their environment and that 2) entities form relationships with one another.

In the KUI model, systems are open and dynamic (living). Their complexity evolves over time with respect to their components. Components can join and leave systems, increasing or reducing their size. We have included two concepts which are not present in the definitions above: the *observer* (who/what is observing the system) and the *view* (the observer's point of view).

We define a system as a set of observable, interacting and interdependent objects, physical or virtual, forming an integrated whole. The system includes different types of objects: entities, observers, and views (Figure 2).

This model offers a simple way for pervasive computing system designers to describe their application by applying a systemic

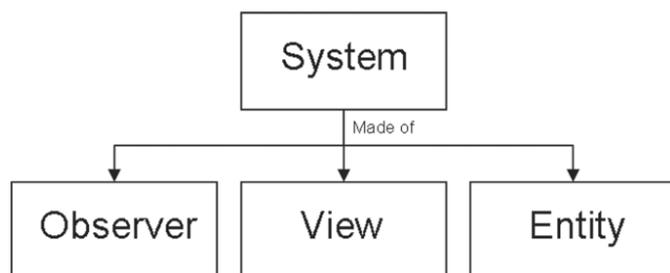


Figure 2. KUI system diagram.

approach. The system is made up of components, objects and rules that once defined can be programmed. The definition of the system can be done using tools like UML. We will now define the objects from which the system is composed.

#### 3.1 Entities

Entities are the observable elements of the system. They can be physical or virtual, living things (users, humans or animals), moving objects (cars or planes) or places (rooms, floors or buildings). An entity has *contexts* and does *activities*.

##### 3.1.1 Contexts

As defined by A. Dey et al. [15], a context is any information that can be used to characterise the situation of an entity. In our model, contexts are used to define the dynamic attributes of an entity. Contexts do not include the activity. The activity is influenced by the environment and therefore by the contexts in which it is done. We will see later that contexts provide relevant information to the observer in the situation analysis. We mainly use the following contexts in our model:

- Identity: it uniquely identifies the entity within the system.
- Location: it gives the physical and logical position of the entity.
- Role: entities can have two roles in the system: *Actor* capable of motion and activity, or *Place* (e.g. room, house, boat) able to contain other entities.
- State: an entity has two possible states: *mobile* (motion capabilities) or *static* (fixed).
- Structure: an entity structure can be *simple* (atomic) or *complex* (containing other entities).
- Relations: two types of relations between entities: *spatio-temporal relations* (physical connection between entities like "inside" or "next to") and *interactional relations* between actors (needed to carry out complex activities).

Other contexts can be defined for an entity and would depend on the characteristics of the system. For instance, temperature or light intensity can be useful contexts for observers.

#### 3.2 Activities in places

Activities are controlled within a place. Places have rules that determine the authorised, forbidden and negotiable activities.

We introduce the concept of white and black activity lists. White-listed activities are the authorised activities that can be carried out with no reaction from the observer. They are accepted as such. Black-listed activities are, on the contrary, forbidden and provoke an immediate reaction from the observer. We also take into consideration what we call the "grey" list. If an activity is not explicitly declared in the white or black lists then it is "negotiable" and gives the freedom to evaluate it and make an inference from the situation. Activity lists allow the observer to quickly react when something is going on in a place by simply checking if the ongoing activity is explicitly present in one of the lists.

#### 3.3 Observers and views

The second part of the system consists of observing the entities. Observers are the agents which collect and analyse information (activities and contexts) about actors and places and possibly react to situations in which the actors could be. Observers have specific roles and analyse one or a small number of situations.

To illustrate this concept, let us take the example of a family house where several rooms (kitchen, living room, bedrooms) afford different activities. Observers are placed in each room

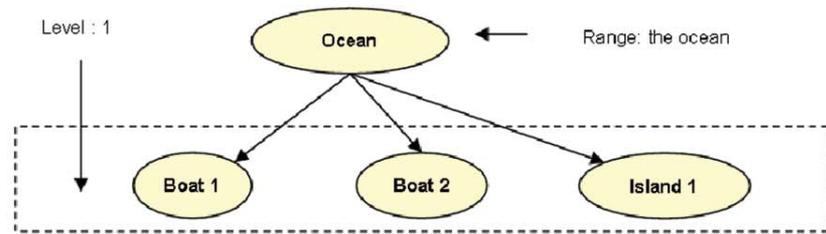


Figure 3. Concept of view in KUI.

in order to evaluate the situations of the actors taking into consideration the actor's activity and context.

Observers are unobtrusive and work in the background without being noticed by the observed entities (Weiser's Calm technology concept [16]). They never interfere with the user's activities and report only critical situations to the higher level. However, any entity is aware of being observed and can decide to allow or forbid its observation under specific conditions, for instance, in certain places at certain times.

### 3.3.1 Views

The entities are observed from certain points of view. Observers can select different points of view to analyse the same situation. Each point of view represents a focus on the situation. Many observers can use similar views for a different situation analysis. A view is a multi-dimensional filter placed between an observer and the entities. We have 2 dimensions in our model of view: range and level.

As shown in Figure 3, the range is the parameter that influences the scope of the observation (e.g. the ocean or only a cruise boat) and the level is the parameter which gives the granularity of the observation (e.g. decks or decks and cabins or passengers).

## 4. An activity-based model for situation awareness

We now define how the kinetic information from the different entities is processed and how a situation is derived from simple movements. Context-aware systems often consider the user's external parameters such as location, time, social information and activity to characterise a situation. In our model, we bring a new point of view to situation characterisation by considering the activity and the context as separate elements where an activity can be interpreted in a context in order to fully understand a situation.

### 4.1 Situations

In [17], Y. Li and J. Landay propose a new interaction paradigm for Ubicomp based on activity (activity-based ubiquitous computing). In their model, the relation between activity and

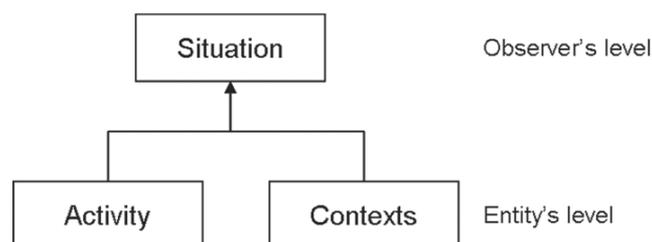


Figure 4. Situation diagram.

situation is defined as follows: An activity evolves every time it is carried out in a particular situation. A situation is a set of actions or tasks performed under certain circumstances. Circumstances are what we call contexts.

According to Loke, the notion of context is linked to the notion of situation [18]. He proposes the aggregation of contexts (perhaps varieties of contexts) in order to determine the situations of entities. In that sense the situation is thought of as being at a higher level than context. Loke makes a distinction between activity and situation and considers an activity as a type of contextual information to characterise a situation.

Our model of situation combines the two visions and we define it as follows: A situation is defined by activities performed by entities with associated contexts (Figure 4).

### 4.2 Context-awareness

As mentioned by A. Dix [19], the main challenge of pervasive computing is *where computers are* and the challenge of context-aware computing is *what it means to interact with computers*. Context-aware applications use contextual information to automatically do the right thing at the right time for the user [18] and often consider that the most important contexts are the location, identity, time and activity [15].

### 4.3 Activity

For Loke [18], activity typically refers to actions or operations undertaken by human beings such as "cooking", "running" or "reading". For Y. Li and J. Landay [17], an action like "running" is not considered as an activity because it focuses on an immediate goal. For Kuutti, in [20], an activity is the long-term transformation process of an object (e.g. a user's body) oriented toward a motive (e.g. keeping fit). The notions of "long term" and "immediate" allow the separation of activities and actions. In our model (Figure 5b), we consider an activity to be made up of detected motions aggregated into operations and actions, and it is an input for observers.

## 5. uMove: the KUI development API

In this section we describe the JAVA API needed to develop KUI-enabled applications. uMove is the 2nd JAVA-based implementation of the KUI concepts [22], [9] and it is divided into three layers in order to have a clear separation of concerns (Figure 5a).

The sensor layer contains all the widgets representing the logical abstraction of the sensors connected to the system. Then we have the entity layer in which we find the logical representation of the physical users, objects or places being observed. The activity manager aggregates the motion events into activities and makes them available to the observer. The observation layer analyses the current situation of the entity based on the current activity and

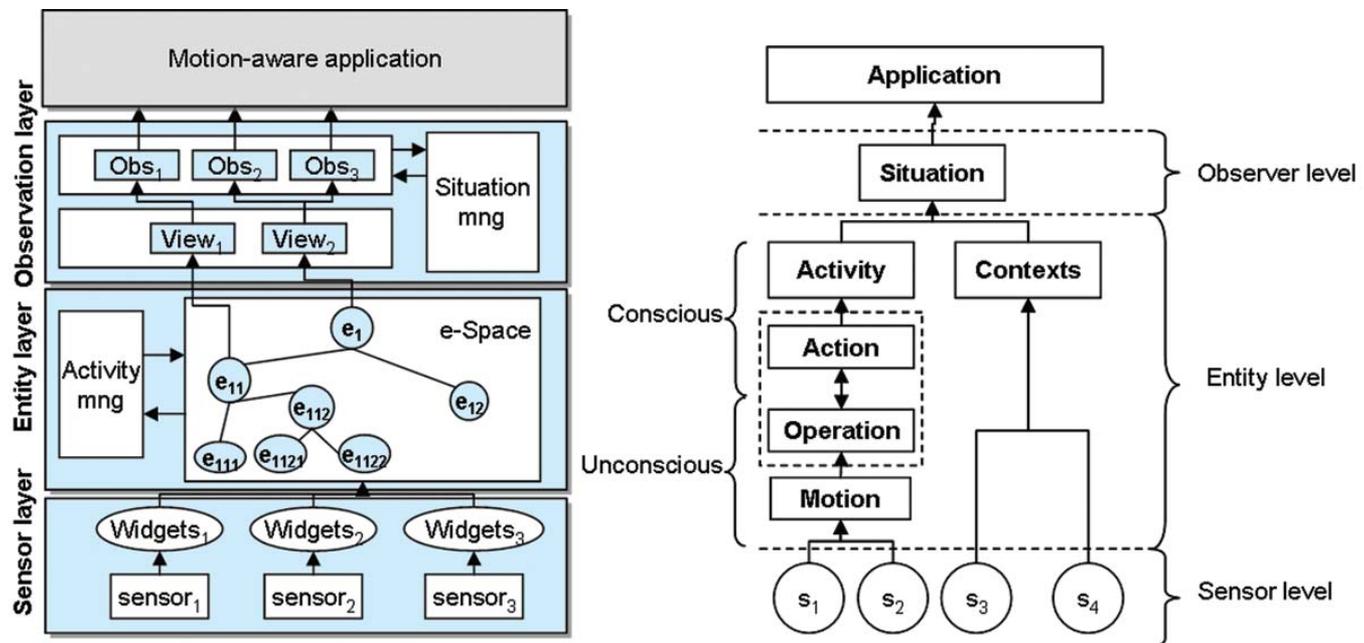


Figure 5. a) uMove architecture, b) motion-aware model.

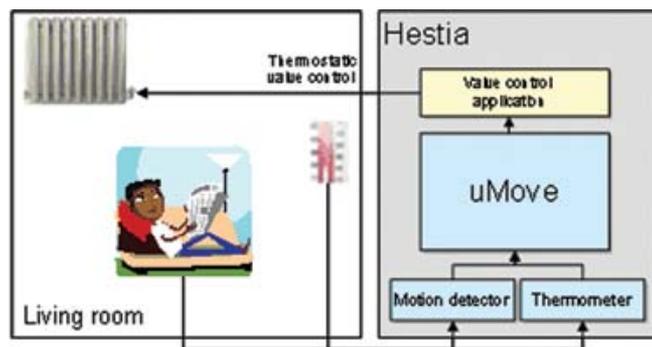


Figure 6. General diagram of Hestia.

contexts. Observers send events to the application according to the detected situations. This model allows the programmer to concentrate on the specific needs of the application without worrying about the communication between sensors (widgets), users or objects (entities) and their management (creation, removal, modification). The activity classes must be specifically developed and can be combined to enable complex motion-pattern recognition. Situation managers, like activity classes, are developed for the analysis of specific situations.

## 6. Hestia: Heating System Optimiser

We now present a project that implements the concept presented in section 2. With Hestia<sup>17</sup>, we propose an application that optimizes existing heating systems by remotely regulating the radiator temperature according to the user's activities and needs (Figure 6). The goals of this project are 1) the reduction of energy consumption and 2) compatibility with a majority of existing heating systems without high cost of transformation.

### 6.1 User's activities and contexts

The Hestia project focuses on a family house with bedrooms, a living room, a kitchen, bathrooms and the members of the family. The user's activities are classified into 3 categories:

Active, Quiet and Resting (Table 1). The contexts used to analyse the user's situation are mainly the bare temperature of the observed room and the time of day. Table 1 classifies the activities, the time of day, the typical body temperature and the expected room temperature.

The situation algorithm is based on the classification in Table 1.

### 6.2 Software architecture

Hestia contains three main components: the physical sensors, uMove and the valve control system (Figure 7). The sensors are connected to the systems via widgets. In this version of the project we have chosen accelerometers to capture the user's motions rather than a camera-based technology such as EyesWeb<sup>18</sup>. The user's location is determined with RFID tags and the temperature is provided by thermometers installed in each room. At the uMove level, the entities representing the house (e1), the rooms (e11, e12) and the users (e111, e112) are created and managed at the Entity layer (Figure 5a). Each user is attached to an Activity Manager which receives the detected motion from a motion detector. Each room is observed by an observer and any activity of a user present in the room is analysed by the corresponding situation manager taking as contexts the temperature and time of day. The application level receives a message from the observers about the needed adjustment (e.g. "room 1: cool down"). The valve control unit processes this information and converts it into an electrical signal before sending it to the thermoelectric actuator.

### 6.3 Hardware

For the first version of the project, we have chosen to use two types of sensors: phidgets<sup>19</sup> and SunSPOT<sup>20</sup> devices. The location and temperature data are provided by Phidget RFID devices and Phidget temperature sensors respectively. The user location and identification is given by the RFID locator (a JAVA class). Each user carries a passive RFID tag, and RFID readers as well as temperature sensors are installed in each

<sup>17</sup>Greek goddess of home.

<sup>18</sup><http://www.infomus.dist.unige.it/>

<sup>19</sup><http://www.phidget.com>

<sup>20</sup><http://www.sunspotworld.com/>

Class of activity	Activities	Time of day	Body temp.	Environment Temp.
Active	Playing games, moving, dancing	All	warm	Cool
Relax	Reading, watching TV, Listening to music	All	cool	Warm
Resting	Sleeping, resting	Night	cool	Cool

Table 1. User's activity classification.

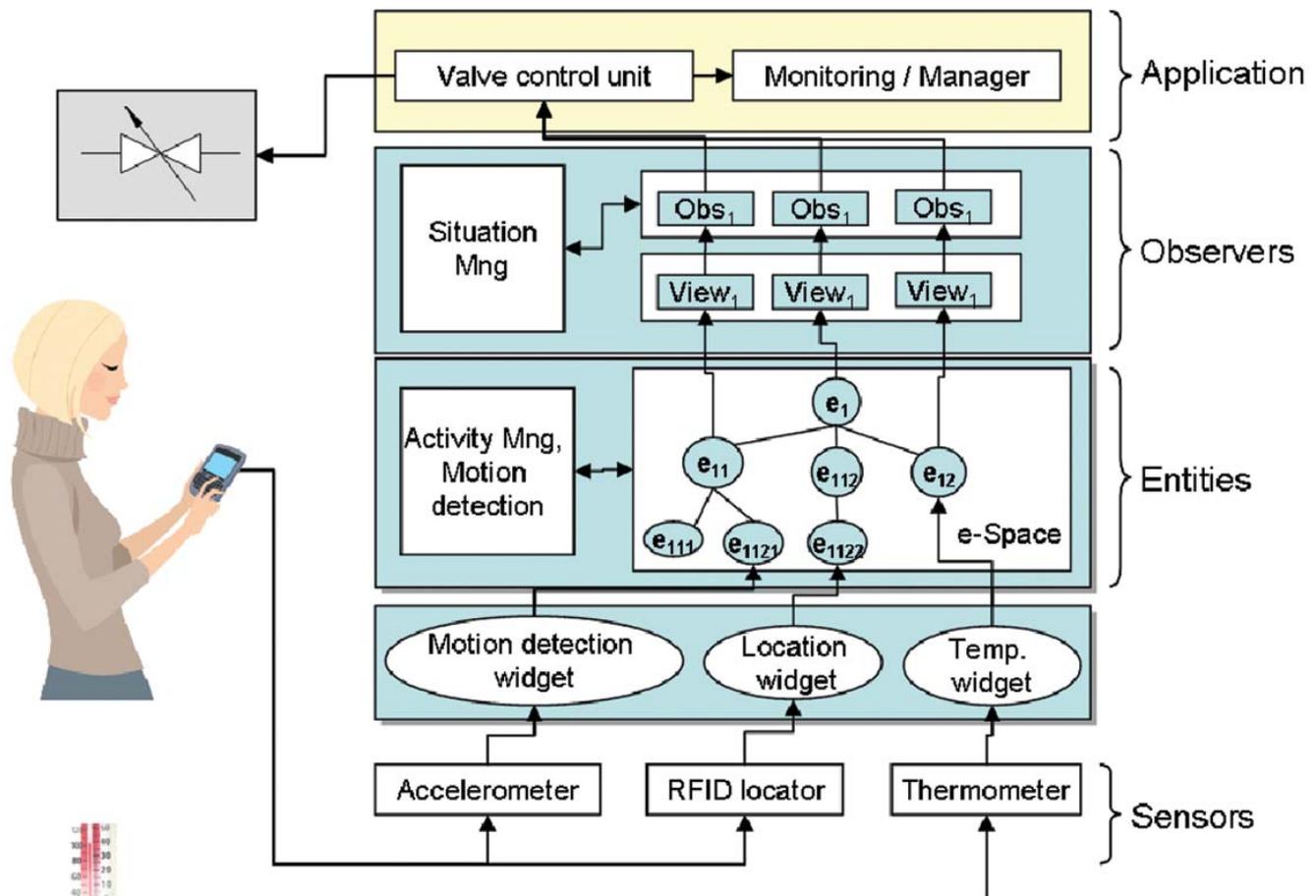


Figure 7. Functional diagram of the Hestia project.

room. User's motions and their body temperature are detected with the SunSPOTS equipped with 3 axis accelerometers and a temperature sensor. Each user carries a SunSPOT device which transmits a continuous flow of acceleration data and temperature values to the motion detection and user temperature widgets. The data are then processed within the uMove API and the valve controller application. The radiator valves are controlled by electrical actuators such as the Danfoss TWA Standard Actuator series<sup>21</sup>.

As mentioned above, we are also working on a low cost solution in terms of hardware. The goal is to provide an "easy to install" solution.

## 7. Conclusion

This article presented the importance of greenhouse gas effect reduction and proposed to explore a new way of controlling house heating. We pointed out that, according to Swiss and European statistics, about 40% of GHGs are produced

by homes or industries and that building heating is partly responsible. The problem is dramatic if we extend this proportion to the entire northern hemisphere. The actual heating systems are in general manually set to maintain a given temperature and the few automated ones that exist do not take into consideration human activities inside the building.

We propose that a user's activity and motion should be used as additional parameters to automatically adapt the temperature in different rooms in order to avoid inadequate temperature settings and/or user behaviour resulting in the waste of energy. We also introduced the Kinetic User Interface concepts and identified their usefulness in a particular use case: the Hestia project. The uMove Java API was presented as a tool for developers of Smart Heating Systems willing to integrate the user's activity and context into their applications. Finally, we presented the Hestia project aimed at optimising existing heating systems by taking into consideration the classification of user activities and low-cost heating system hardware adaptation.

We believe that heating system optimization as well as good building insulation can help to reduce the consumption of energy

<sup>21</sup>[http://heating.danfoss.com/xxTypex/74981\\_MNU17378951\\_SIT54.html](http://heating.danfoss.com/xxTypex/74981_MNU17378951_SIT54.html)

agents such as heating oil or coal and therefore reduce the production of GHGs.

### 7.1 Future work

We are currently building the first prototype of the KUI-based heating system optimiser and bootstrapping the learning of user behaviour associated with the activities that are relevant for heating adaptation. As soon as the first prototype is running we plan to carry out a series of tests and assess both the usability of the system (i.e. assessment of the unobtrusiveness of its interfaces according to [23]) and the impact on energy consumption.

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## Author's biography



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