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ORIGINAL ARTICLE

**Wolfgang Trumler · Faruk Bagci · Jan Petzold
Theo Ungerer**

Smart doorplate

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Abstract This paper introduces the vision of smart doorplates within an office building. The doorplates are able to display current situational information about the office owner, to act instead of the office owner in case of absence, and to direct visitors to the current location of the office owner based on a location-tracking system. Different scenarios are proposed and a prototype implementation is presented.

Keywords Context awareness · Context prediction · Distributed application · Middleware · Peer-to-peer · Self configuring · Smart doorplate

1 Introduction

Smart buildings represent an important application area of ubiquitous computing that includes context-aware and networked smart appliances. Most smart building technologies are developed for smart home environments, less projects concern office buildings. Several smart home projects track the vision of intelligent houses and household devices. The Adaptive House project [1] of the University of Colorado developed a smart house that observes the lifestyle and desires of the inhabitants and learns to anticipate and accommodate their needs. The adaptive system controls basic residential comfort systems – HVAC (heating, ventilation, and air conditioning), water heater, and interior lighting. Occupants are tracked by motion detectors, and a neural network approach is used to predict the next room the person will enter and the activities he will be engaged.

The Aware Home Research Initiative (AHRI) [2] at the Georgia Institute of Technology has built a living laboratory for research in ubiquitous computing for everyday activities. Person recognition and tracking is done by a Smart Floor system, which uses the identification of inhabitants by their walking patterns. Many different sensors scattered to all rooms collect environmental context information, what is used to offer different services.

At the University of Cambridge the Opera group has developed the Cambridge Event Architecture (CEA), which is based on a publish, register, notify paradigm. An application using the CEA is the Active House [3] demonstration where events are used to link a range of automated appliances within a virtual house. The appliances can both produce and receive events, i.e. they can act as an event source and sink at the same time, and publish, register, notify and receive events. The owner of the house may wish to express complex policies on how it should behave in terms of combinations of event occurrences. Therefore a simple composite event algebra is provided allowing more complex and useful interaction between event sources and sinks.

Experiences collected by these projects can partly be transferred to work environments, however, none of these projects targets office buildings.

Our project focuses on smart doorplates within an office building. A smart doorplate resembles the vision of a semi-transparent door that displays the current working situation of the employee. In the case of absence, the doorplate should be able to act instead of the office owner and perform simple secretary tasks (accept/forward messages, notify visitors of the current location of owner or return time). The office owner should be able to control the information that is displayed on his doorplate.

Two projects pursue smart doorplates with related concepts. The doorplate [4] of Teco, Karlsruhe, is able to display the situational context ('meeting') of persons within a meeting room depending upon the number, location and states of smart coffee mugs [5] within the room. The doorplate project at the University of Lancaster [6] is able to display notes for visitors and change them remotely, e.g. by sending a text message (SMS)

W. Trumler (✉) · F. Bagci · J. Petzold · T. Ungerer
Institute for Computer Science,
University of Augsburg,
86159 Augsburg, Germany
E-mail: trumler@informatik.uni-augsburg.de

Fig. 1 Main screen

Fig. 2 Present persons

from the office owner. The visitors themselves can post messages for the office owner using the doorplate as a kind of notepad. Both projects apply the doorplate in a rather restricted application scenario, in contrast to our project, which covers much wider scenarios. Concerning the implementation, all the above-mentioned projects use centralised storage and communication mechanisms instead of *ad hoc* networking. The communication is limited to messages instead of services or agents.

The next section shows our vision of smart doorplates within an office building. Section 3 specifies the application requirements of a prototype system and Sect. 4 describes the system architecture. Section 5 introduces our prototype implementation, and Sect. 6 gives more details on the implementations of context awareness and context prediction. The paper ends with the conclusion.

2 The vision of smart doorplates

The following scenarios demonstrate applications of smart doorplates in combination with a visitor/employee tracking system and additional sensors:

Scenario 1: Smart doorplate as signpost

The doorplates act as signposts within the office building to direct visitors to the employee sought. We assume that the visitor identifies himself and who he wishes to meet in the lobby to the receptionist, receives an identification tag and is directed to the office of the employee. The direction system is implemented by the doorplates. As soon as the visitor is in the vicinity of a doorplate, the doorplate points (e.g. by means of displaying an arrow) in the direction of the office sought after. Assuming that a single visitor passes several smart doorplates on his way to the office, a direction pointer is sufficient and most appropriate. If multiple visitors linger in the vicinity of a doorplate, a synchronisation of competing display information may be necessary, e.g. by combining multiple directions by a single arrow or by showing different arrows for the visitors. If the employee is not in his office but within the building, the doorplates may direct the visitor (or a colleague) to the current point of location of the employee, assuming that the employee is tracked by a tracking system.

Scenario 2: Visitor in front of the office
and office owner present

In the case of the presence of the office owner, several possibilities arise:

- The office owner is on the phone and may not be disturbed. The doorplate displays the state ‘phoning’ to prevent disturbances. When the phone call is finished, the doorplate notifies the waiting visitor and ushers him in.
- If two or more colleagues share an office, it may be that one colleague is busy, whereas the requested employee is ready to meet the visitor. The doorplate allows the visit if it is for the unoccupied office member using the information provided by the receptionist.
- The office owner is in a meeting within his room. The smart doorplate displays that the office owner is present, but should not be disturbed. The office owner may receive a notice of the waiting visitor with the name of the visitor on his notebook or PDA, and he may answer by a notice, when the end of the meeting can be expected. All visitor messages are send and received through the smart doorplate without disturbing the meeting.
- The office is being used as a meeting room. The doorplate may display that the room is occupied, which meeting it is, the list of attendance, time of end of meeting, etc. Such information may be drawn from an electronic meeting protocol.

Scenario 3: Visitor arrives in absence of office owner

If the office owner has locked his office and a date is shown in his electronic schedule, the doorplate may

Fig. 3 Direction to employee

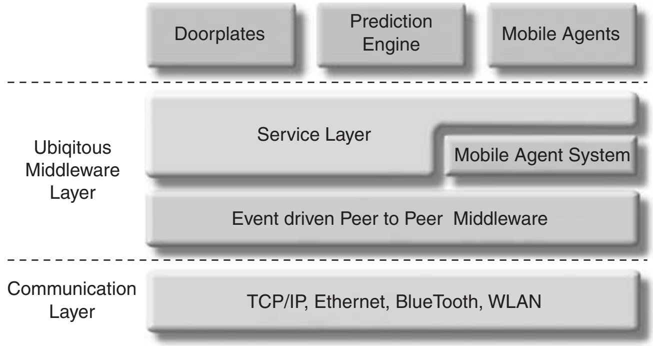

Fig. 4 The smart doorplate system architecture

display his current location (in house, out of house or more details) and the time at which he is expected back. If the employee is located in a different office, the room number may be displayed and the surrounding doorplates used as direction pointers. Alternatively, the system could predict if the employee is coming back soon and recommend the visitor to wait. The visitor may leave an oral or written message at the doorplate (microphone or touch panel presupposed). On return, the office owner is notified of the message and may display it on the doorplate or within his office. Urgent messages may even be forwarded to the current location of the office owner (e.g. by LAN, WLAN, or SMS).

Scenario 4: Return after absence

The office owner arrives in the morning or after a meeting at his office. The smart doorplate recognises him by his identification tag, and displays the number of visitors that left a notice, the number of missed phone calls and email messages. Important visitors, urgent phone calls or emails may be highlighted. The display must be configurable to meet the individual needs of the office owner. The displayed information that may contain personal data should only be displayed for the office owner and potentially if nobody else is in the vicinity. This information should only be summarised information, text and oral messages should be displayed within the office, not at the doorplate.

3 The smart doorplate prototype system

Several networked hardware and software elements are necessary for a prototype system:

- the doorplate (a display, preferably a touch screen, and a microphone connected to a network);
- the person tracking system (identification tags and tag readers);
- additional sensors (to detect if a door is open) and actuators (e.g. electronic door locks);
- the system software and middleware to connect the appliances.

The technical implementation of the smart doorplate system should be realised such that a minimum of hardware development is required.

Our prototype currently under development to test and evaluate the vision focuses on the first scenario. Figure 1 shows the main screen of the smart doorplate with the room number, the names of the two office owners, their presence, and additional information Figure 2 displays the names of all people that are currently present in that office. Figure 3 shows the room number of the current location of the sought employee and an arrow pointing to that room. Prediction information may be used to predict the next location of the sought person and to direct the visitor to that place.

The prototype version of the doorplates simply uses Compaq iPAQ PDAs, which fulfil all the hardware requirements for the scenarios providing a touch screen, Bluetooth and Infrared interfaces for the wireless communication with other devices, and a microphone for recording the visitor's messages.

In-door person tracking can be done by a number of systems (see Hightower and Boriello [7] for an overview). We choose a transponder technology to detect the locations of persons within the building. This technology is composed of transponders (RFID tags) worn by people and appropriate RFID tag readers. People can be identified within a reading range of up to a few meters. An accurate determination of the position is not required by our application. Currently, we utilise the RFID system of Texas Instruments [8].

We also need door sensors to enable the system to detect whether the door is open, closed or locked. This information is deemed important because the doorplate's display information may be superfluous when the door is open.

Access to an electronic calendar (e.g. Microsoft Exchange) on the computers in the office can be used for

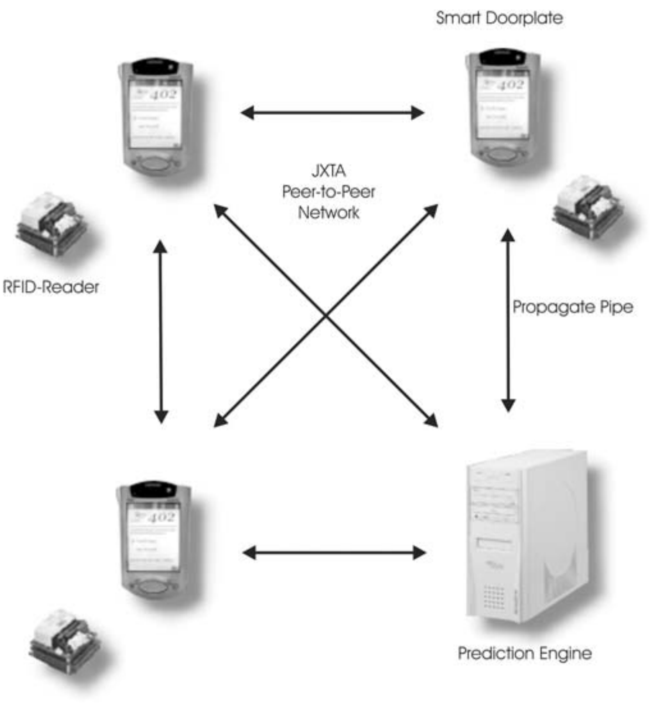

Fig. 5 Sample application

extracting information in the absence of the office owner. The ubiquitous middleware connects the components to each other and to the computers in the offices, so that the doorplates can exchange information with the office computers and the sensors.

4 System architecture

The first implementation of our prototype software was based on a client/server-system architecture, to realise communication between the doorplates and a single server with the information about all the doorplates and the locations of the employees. Doorplates needed to retrieve the current information about their room in a cyclic fashion, which led to high network traffic, even if there were no changes.

Our current Ubiquitous Middleware (Fig. 4) is based on an event-driven approach based on a peer-to-peer system that decouples the Service Layer from the various networking techniques. The advantages are that we can omit the central storage, and that we achieve a completely self-configured system.

Currently, the Service Layer of our Ubiquitous Middleware consists of a Location Service, a Direction Service and a Prediction Service.

The Location Service evaluates the sensor data from the tracking system and generates location information of the tracked persons. Currently, we use RFID tag readers for the location detection.

The Direction Service directs the visitor to the current location of the sought person. It uses mobile agents, which jump from doorplate to doorplate to locate the person sought after, because each doorplate has only local information about its vicinity.

The Prediction Engine receives information about the movements of the office owner(s) from the Location Service. It can predict the next location based on the habitual movement pattern of the office owner. The Prediction Service retrieves the context prediction from the Prediction Engine, and can be used by a doorplate to find the next location of an office owner.

5 Prototype implementation

The prototype implementation is composed of single doorplates, which can act as stand-alone units with restricted functionality. The customisation of a doorplate is done by configuring the room number and the names of the people residing in that room. Each doorplate only stores the information associated with the room it stands for. If the doorplate is informed that a person has entered or left the room, it updates the local storage to reflect the actual situation. As a result, the information that forms the complete application context is distributed across all doorplates.

The communication is based on the JXTA [9] peer-to-peer platform. Every doorplate represents a peer. The Prediction Service and Direction Service are implemented as peer group services. Both can be implemented decentralised on the different doorplates. However, we decided to implement both services on a PC, which is a peer of its own, because of the weak processing power of the iPAQs (see Fig. 5).

JXTA Messages are sent over so-called unidirectional, bidirectional or propagate pipes. Unidirectional pipes can send a message in only one direction from the sender to the receiver. The sender uses an output pipe to send the message to the receiving peer, which needs an input pipe to receive the message. Over a bidirectional pipe both peers can send and receive messages. Propagate pipes are unidirectional pipes where the message is sent to all peers that have an input pipe for that propagate pipe. This means that a message sent by one peer can be received by many peers.

If a new doorplate is added to the system there is no information available other than its room number and the inhabitants. But as soon as there is a location change, the new doorplate is informed via a propagate pipe and can update its local information. So the new doorplate is smoothly integrated in the application. The application context is updated automatically by new messages sent, when there is a change detected by the Location Service. The doorplate needs only the information about the room number and the name of the office owner. Everything else, like the location of a person and the direction leading toward that location, can be determined during runtime by using the mechanisms which the JXTA peer-to-peer network offers.

If a doorplate is reconfigured by changing the room number or the names the reconfiguration is reflected immediately, and any information related to the room number will be stored by the newly configured doorplate from now on. If a doorplate becomes out of order or is unreachable only for a while, its information will be lost to the application. This means that the information concerning that room will no longer be stored or updated, and that the information already collected (e.g. who else is in that room) is no longer available.

However, as the location of the person will change sooner or later, his new location will be updated by the doorplate controlling the room entered, and the context will again reflect the current state. If the doorplate resumes work and its local context is out of date, it might answer if it is asked about a person's location. Because we store the time when an information change occurs, there might be two answers to that request with two different timestamps, and the newest one will be used. The doorplate will update its information over time as it is informed by location changes, which will update the local information.

6 Context awareness and context prediction

Instead of a centrally stored context, our implementation uses distributed context information. Only the context information, which people are in a room, is relevant for the scenarios described. Every doorplate stores this information for its room, and the total application context is made up by these distributed contexts.

If a location change is detected, all doorplates receive a location message. This message contains the room a person entered and the identification of the person. A doorplate that receives such a message must update its local context. If the given room number belongs to the doorplate, the name of the person is added to the list of present persons. If the person is the office owner, the doorplate will display an icon beneath the person's name. Otherwise, if the list of people present on the doorplate contains the received name of the person, meaning the person has left the room, it will remove the person from the list of people present and, if necessary, remove the icon on the screen.

A possible enhancement is the following: if neighbouring doorplates store at least some messages for a defined amount of time, the context could be built even in case of a faulty doorplate.

In our application the context prediction is restricted to prediction of a person's future location. The actual implementation uses a Prediction Service as a peer group service, which can be used by any doorplate.

The Prediction Service uses a replaceable prediction engine to evaluate different prediction algorithms. The challenge is to transfer known prediction algorithms like Bayesian networks, neural networks and Markov chains to handle context information. We actually use an algorithm based on Markov chains [10]. The prediction engine records the previous locations of every person. With these patterns and the probabilities of the possible locations, a person's next location is predicted. The Prediction Service informs the prediction engine in case of location changes, and the prediction engine will update its information.

A visitor who misses someone can ask for the actual location of a person by clicking on the person's name at the doorplate. The doorplate asks the Direction Service, which sends a mobile agent to locate that person and informs the doorplate when the person is found. Next, the doorplate can activate the Prediction Service to get a prediction of the person's next location. At the moment it is not possible to give hints like "will be back in five minutes", because we do not deal with time information yet. For now, we only anticipate the next location with a given probability, depending on recognised patterns.

7 Conclusion

We introduced the vision of smart doorplates that are able to display current situational information about the office owner, to act instead of the office owner in the case of absence, and to direct visitors to the current location of the office owner based on a location-tracking system. Our prototype focuses on the scenario of a visitor direction service, and is based on a peer-to-peer middleware architecture that proved as advantageous over a client/server system.

Context awareness is still limited to location awareness and context prediction to next location prediction. We are currently working towards an extended prototype system that spans two floors within our department building. Movement patterns of us and our colleagues will show how far next location prediction can be achieved with the various prediction algorithms.

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