# The Active Badge Location System

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Integration of telephone systems with computer systems is an important part of the development of the automated office. Much work has already been undertaken integrating digital voice and data into a single network [1] but there has been less commercial effort invested in improving the telephone interface. Although these interfaces are functionally very sophisticated they are mostly cryptic and their operation is difficult to remember. The features most commonly used by PBX clients are 'call transfer' and 'call divert' or 'follow me'. In the majority of cases the execution of these features could be automated by the PBX if it had information about the current location of its clients.

A solution to the problem of determining location information has further application, for example, to help a receptionist locate employees without a public-address system or without telephoning all the possible locations at which they might be found. These kinds of solutions can cause a great deal of irritation and disruption to other employees. Further advantage can be gained from location information by allowing PBX users to define rules governing when a call transfer is allowed. For instance, where you are and who you are with should affect this decision. Most people would prefer not to take unexpected telephone calls when they have just been called into their bosses' office, and there are many other instances for which call control based on location can be used effectively.

## 1 Existing Location Systems

The conventional solution used for personnel location is the 'pager system'. In order to locate a person a signal is sent out by a central facility that addresses a particular receiver unit (beeper) and produces an audible signal. In addition, it may display a number to which the called-party should phone back (some systems allow a vocal message to be conveyed about the call-back number). It is then up to the recipient to use the conventional telephone system to call-back confirming the signal and determine the required action. Although useful in practice there are still circumstances where it is not ideal. For instance, if the called party does not reply the controller has no idea if they: 1) are in an area where the signal does not penetrate 2) have been completely out of the area for some time 3) have been too busy to reply or 4) have misheard or misread the call-back number. Moreover, in the case where there are a number of people who could respond to a crisis situation, it is not known which one is the nearest to the crisis and therefore the most suitable to contact. A 'tagging system' does not have this problem. It provides information about where the tag is at that moment or in the worst case when it was last sighted. In both of these cases the information is positive and available to be acted upon. Morever, tag technology is now sufficiently advanced that electronic tags can be made small, inexpensive and will consume little power, however, up until now their main application has been in the area of logging and access control [2]. The usefulness of a location system is not restricted to office applications: another large application area is the

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hospital environment in which it is beneficial to keep track of both staff and patients.

## 2 Active Badge Design

The solution has been to design a tag in the form of an 'Active Badge' that emits a unique code for approximately a tenth of a second every 15 seconds (a beacon). These periodic signals are picked up by a network of sensors placed around the host building. A master station, also connected to the network, is given the task of polling the sensors for badge 'sightings', processing the data, and then presenting it in a useful visual form. The badge was designed in a package roughly 55x55x7mm and weighed a comfortable 40g.

Figure 1: The ORL Active Badge Design

Pulse-width modulated infrared (IR) signals were used for signaling between the badge and sensor [3], mainly because: IR solid-state emitters and detectors can be made very small and very cheaply (unlike ultrasonic transducers); they can be made to operate with a 6m range and the signals are reflected by partitions and therefore are not directional when used inside a small room. Moreover, the signals will not travel through walls unlike radio signals that can penetrate the partitions found in office buildings. Infrared communication has been used in a number commercial applications ranging from, the remote control of domestic appliances to, data backup links for programmable calculators and personal organisers [4], and at the more novel end of the market IR-based local area networks [5]. Because IR technology has already been exploited commercially, it is inexpensive and readily available for developing new applications such as the 'Active Badge'.

An active signaling unit will consume power; therefore the signaling rate is an important design issue. Firstly, by only emitting a signal every 15 seconds the mean current consumption can be very small with the result that 'badge sized' batteries will last for about one year. Secondly, it is a requirement that several people in the same locality must be detectable by the system. Because the unique signals have a duration of only one tenth of a second there is, approximately, a 1/150 chance that two signals will collide when two badges are placed in the same location. For a small number of people there is a good probability they will all be detected. Even so, to improve this chance the beacon oscillator has been deliberately designed around low-tolerance components: it is very likely that two badges, which by chance are synchronised, will have slightly differing frequencies and lose synchronisation in a few minutes.

A disadvantage of an infrequent signal from the badge is that the location of a badge is only known, at best, to a 15 second granularity. However, because in general a person tends to move relatively slowly in an office building, the information the Active Badge system provides is very accurate.

The Active Badge also incorporates a light-dependent component that with reduced lighting increases the period of the beacon signal to a time greater than 15 seconds. In ambient lighting conditions for a room this effect only slightly modifies the period, but adds sufficiently random components to the beacon period to remove badge synchronisation problems. However, in a significantly dark room e.g. at night, or in a closed drawer; the period increases to a point where the badge is effectively turned off. If the badge is placed in a drawer out of office hours, at weekends and during vacation, the effective lifetime of the batteries is increased by a factor of 4. Note that the more obvious solution of a 'switch' was considered a bad idea as it was likely that a 'badge user' would forget to turn it on. Other options for switching the device on included a tilt switch and an accelerometer although the size limitation of a badge precluded using them in the initial experimental system.

## 3 Badge Sensor and Telemetry-Network Design

To detect Active Badges in transit through a building, a sensor network must provide good coverage. Sensors can be designed as inexpensive, easy to manufacture units. The ideal system would take advantage of existing computer networks as a means of gathering badge sightings and relaying the data back to a central server for processing. A design was conceived that would allow an independent network to support up to 128 sensors controlled from the RS232 port of any standard workstation. This approach was advantageous because it also allowed for a network of workstations, typically joined by an Ethernet, to support multiple badge networks, with the data being relayed back to one master server by conventional network protocols.

Figure 2: Badge Sensor and Telemetry-Network

A prerequisite for the badge network was that it should be able to link all areas of any building with an arbitary topology. Power would need to be fed though the network because the sensors would be too numerous and distributed in too many remote places for them to be supplied by power locally.

Given these constraints the badge sensor-network has been designed as a low-cost 4-wire system (figure 2). Two of these wires carry the network power-supply, the third carries the serial addressing information allowing the network-controller to nominate a station, and the remaining wire carries data back to the network-controller. Conventional telephone twisted pairs are used, and indeed there may be cost advantages in some buildings where spare telephone cables already exist. The data-transfer format is logically the same as RS232 but the network is physically a wired-OR system. The consequence is that by using a simple level-shifting interface-box any computer with an RS232 port can be used as the network master.

In order that the network master should not have to poll the sensors at high speed to avoid data loss (e.g. if two badges in one room signaled with a very short delay between them), a FIFO has been designed into each sensor that is capable of buffering 20 badge sightings. This allows the network master to multiplex its time between polling the network, manipulating badge data, and making the data available to clients.

# 4 An Active Badge Application

The initial application of this system (the demonstration system) has been designed as an aid for a telephone receptionist. The system provides a table of names against a dynamically updating field containing the nearest telephone extension and a description of that location. The format fits onto a standard PC display and is shown in more detail in figure 3. A third field shows the likelihood of finding somebody at that location in the form of a percentage. If it is below 100% it shows the person is moving around, and if they have not been sighted for 5 minutes it displays the last time and location at which they were sighted. The last sighted location is still the best clue a receptionist may have to locate somebody and indeed there may be other work colleagues in that area who will know why that person is no longer there. Beyond 24 hours the last day a badge is sighted is shown in abbreviation and if there are no sightings detected for a week or more, the person is indicated to be 'AWAY'. This format was found to be useful and did not overload the display with too much information. In addition to the display a command interpreter allows simple investigations to be performed on the system. The commands found to be of most use are listed below:

- **FIND (name)** Provides the current location of the named badge and if it has recently moved, a list of all the locations it has been sighted at in the last five minutes along with the likelihood of finding it at each.
- **WITH (name)** Locates a named badge and provides information about other badges that are in the immediate locality of that badge.
- **LOOK (location)** Allows an investigation to be made of the badges that are currently near to the specified location.
- **NOTIFY (name)** An alarm mechanism that generates an audible indication of when the named badge is next sighted after executing the command. 'NOTIFY' is particularly useful when trying to deliver an urgent message to a member of staff who is out of the office on business for long periods of time.

Another useful feature for locating a colleague is a location history mechanism. This command has also been built into the ORL demonstration system.

- **HISTORY (name)** Generates a condensed report of the location history for the named badge during a one-hour period. The current implementation of the system only holds this information as a dynamic data-structure and it is not logged to a permanent storage medium.

In its existing form the demonstration system does not perform any automatic routing of telephone calls. It requires a receptionist to look at the display of locations and then redirect the telephone call in the standard way. At ORL some low-level interfaces have been built that allow certain types of PBX to route telephone calls semi-automatically. However, due to the proprietary nature of PBXs it is not possible to design a comprehensive solution without the help and consent of a company in the telecommunications business, and this has proved difficult to obtain.

# 5 Location Server Design

The work at ORL has shown a location server can usefully be thought of as a four layer system.

- **Network Control** – The network controller is responsible for polling all sensors on the network. It may be designed to adopt a polling strategy that is biased towards testing sensors that are known to have recently seen badges, more regularly than those that have not. Errors in badge-ID format should also be picked up in this layer and erroneous data removed.
- **Representation** – Once valid data has been extracted from the network it must be time-stamped and entered into a data structure that relates the ID of the badge that has been sighted, location and time (a triple). In order to obtain information about the recent activities of a badge a convenient representation can be obtained by building a linked-list of these data triples in time-order up to a maximum time (5 minutes was used for experimentation). For some applications it is also useful to maintain a list of badges seen at each location.
- **Data Processing** – An Active Badge network can soon collect a large amount of data. It is necessary to process this data to reflect only the changes in badge locations or provide compressed summaries of the recent history of a badge. If a location server were going to be built as part of a distributed system with the applications running on remote machines, an RPC network interface can be most effectively designed on top of this layer rather that at the Network Control Layer. Some care needs to be put into the server design to compress the location information into a form that does not cause excessive network traffic.
- **Display Interface** – The Active-Badge demonstration-system display uses the location information extracted from the previous three layers as the input for a display function showing textual information about the changing positions of badges. Alternative implementations may choose a graphical display to show the position of badges on a building floor plan using moving icons.

Figure 3: A typical display showing the location of staff at ORL

Further enhancements to the system could be considered if the server had access to knowledge about the architecture of a building. Such a system may be able to make simple predictions. For instance, given the time and the previous locations at which a badge has been detected, it may be possible for the system to predict where a particular person is going. Clearly, in all our lives there are general patterns to our everyday movements and it may be possible to design a badge system that after longer periods of operation can make better predictions.

## 6 Privacy Issues

Clearly a location system has many advantages, but it also raises many social fears. When most people hear about a personnel location system the immediate reaction is generally one of horror. The thought that anybody would wish to put such a device into the work-place is not considered to be favourable on the grounds of personal freedom and an individual's rights. Before the initial trial period at ORL the reaction was one of concern. ORL is a research laboratory containing 32 staff, three of which are administrators, six are contractors, there is one Laboratory Director and a Laboratory Manager, the remainder are engineers. Management requested that everybody should wear the badges for a trial period of two weeks and from then on it was considered optional. In the initial 10 work-days the incidence of telephone calls not reaching the correct place dropped substantially; the main laboratory no longer received a continuous stream of disruptive enquiry calls - the main laboratory was the default place to check for anybody if they were not in their own room. ORL's receptionist had a much easier time and was able to avoid many wasted trips, up and down corridors, trying to find members of staff. Also the perception of clients telephoning ORL was one of good organisation, since the receptionist was able to say with great certainty where somebody was or when they were last seen or the likelihood that they had just taken a lunch break, all without the need to be explicitly informed by the staff. It also gave employees the advantage that when expecting a telephone call they could wander around the laboratory, the printer room, or the coffee room with confidence that the call would still reach them successfully. Groups of people that regularly wanted to hold meetings could find each other easily with very little notice, since they could also access the location information. Other advantages from a security and convenience point of view were that visitors could be easily located during their visits to ORL. For all of these reasons the two-week trial was a success and most people continued to wear their badge quite willingly after this period.

There will always be some days when for whatever reason somebody does not wish to be located. This is easy to solve because the system tracks badges and NOT people. Anybody in this situation can easily remove their badge and leave it on a desk. The Active Badge system will now be fooled into concluding that person is somewhere where they are not. This kind of escape mechanism is not an undesireable system-feature and may be an important factor in making this system acceptable for common use.

Another factor that affects the acceptance of a system of this nature is the security of the data it produces. It is quite possible for a locator system to be devised that allows each person to specify who may locate them and in addition provide information about who has tried to locate them and how much. If this knowledge can be guaranteed, it would soon become clear when the system was being misused. Such privilege systems are well understood and are in common usage to protect computer filing systems. It may be that despite knowing the system can be made to be secure, there will always be a fear that a secret logging system has been installed by the office management. A company that has a bad management policy can of course make life unpleasant for employees with or without a badge system, and this is a different kind of problem.

## 7 Conclusion

The experiments at ORL have shown the 'Active Badge' concept to be very useful. In its experimental form at ORL the badge has become widely accepted for everyday use and improved the working environment. The badge is a device that is limited to providing location information, but with the use of more complex miniature devices such as ASIC technology or low-power micro-controllers a great deal more can be achieved. Two-way communication is one way to extend functionality. A badge that has a display and can receive data can also operate as a pager. An Active Badge in combination with a pager provides the best of both worlds.

A transponding badge can also be used as a key, authenticating itself on entering a secure area. The problem with a remotely operated key is that the signals it sends can be recorded and played back later to masquerade as the same key. By the use of a randomised challenge/response protocol, from the secure area to the key, good protection can be given against this kind of forgery. The basic locator-badge without additional features can also be used in combination with conventional security systems such as motion detectors. Motion detectors warn about all movement that occurs in a building, but the badge system allows a refinement indicating where there is movement accompanied by a badge ID. Movement without detecting an Active Badge would alert security staff to a suspicious situation.

A future badge may also be able to signal several different codes, for instance: a location code, a battery-low code, and codes generated by pressing buttons on the front of its case. The button codes may signal special commands to the controller that modify its behaviour. In the case of telephone call-forwarding a button-press received from a meeting room may stop calls being forwarded there. However, if the badge is seen in another (i.e. the meeting has finished) the meeting room command is now cancelled automatically. This example illustrates an important aspect of badge technology: a signal produced by an Active Badge can have totally different effects at different locations on the network.

Where the Active Badge concept is used and becomes accepted as an office system it may be combined with other building management control-functions such as: fire alarms, security, heating, air-conditioning and lighting control. The Active Badge extends the concept of an integrated building to take into account the location of personnel in that environment.


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