ACTIVE BADGES AND PERSONAL INTERACTIVE COMPUTING OBJECTS

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Abstract

This paper describes a family of Personal Active Badges developed for location of people and devices in the computer environment. Applications include location and paging of individuals as well as control of computer systems. Active Badges are one type of a range of portable computers connected to cordless communication systems that can now be made. Because of their small size and application such devices are referred to as Personal Interactive Computing Objects or PiCOs. A speculative discussion of how such devices may be used in the traditional computing environment is given.

1. INTRODUCTION

By restricting the local computation requirements of a portable device to a basic level, its size and power consumption can be kept at a minimum. A communications link can be used to provide the real computing power elsewhere. Such portable interactive computing objects (PiCOs) fall into the following categories: simplex (transmit only); simplex (receive only); duplex (transmit and receive). The most versatile devices will be in the last category. However, one-way communication can still lead to useful devices, and has the advantage that the size and power consumption can be very small. An infrastructure for testing PiCOs has been designed and is in use at a industrial research laboratory and at a University department nearby. The first PiCOs in use are personal Active Badges. Two types of badge have been developed: the transmit-only Active Badge and the duplex Authenticated Badge.

2. TRANSMIT-ONLY ACTIVE BADGES

2.1 Design

The Active Badge [1] operates as a beacon, regularly signalling a unique code to a network of sensors distributed around the area to be monitored. Sightings are gathered by using a master processor which polls the sensors through a network provided for the purpose. The name and location of a badge wearer can be ascertained by looking up the badge ID in a table and looking up the location where the sighting was made.

The main components of the Active Badge system are shown in Figure 1. The badge is contained in a case 55x55x7mm and weighs about 40g. Infra-red communication was chosen because it is well established in a number of commercial applications ranging from the remote control of domestic appliances to local area networks [2,3]. IR solid-state emitters and detectors can be made very small and cheap (unlike ultrasonic transducers). Pulse width modulated infra-red (IR) signals were used for signalling between the badge and sensor [4]. The infra-red signals have a range of approximately 10 metres and are reflected by

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walls. This means the system is not particularly directional when used inside a small room.

An active signalling unit consumes power, and as a result the signalling rate is an important design issue. By only emitting a signal every 15 seconds, the mean current consumption can be made very small, with the result that small batteries will last for about one year. This low signalling rate also allows several badges in the same locality to be distinguishable 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 high probability that they will all be detected within a short time.

A disadvantage of an infrequent signal from the badge, is that the location of a badge is only known, at best, every 15 seconds. However, because at this granularity a person tends to change locality infrequently, the information the Active Badge system provides is sufficiently accurate. The badge is equipped with a single press button which can be used to make an out of sequence transmission for passing a signal to the master processor or for testing.

The Active Badge also incorporates a light dependent resistor (LDR) that, with reduced lighting, increases the period of the beacon signal to an interval greater than 15 seconds. In ambient lighting conditions this effect modifies the period only slightly while adding random components. This helps to further remove badge synchronisation problems because it is very unlikely that two badges will continuously have the same lighting conditions and keep in step. However, in a significantly dark room e.g. at night, or in a closed drawer, the period increases to a point where the badge uses very little power (although it can still be found). If the badge is

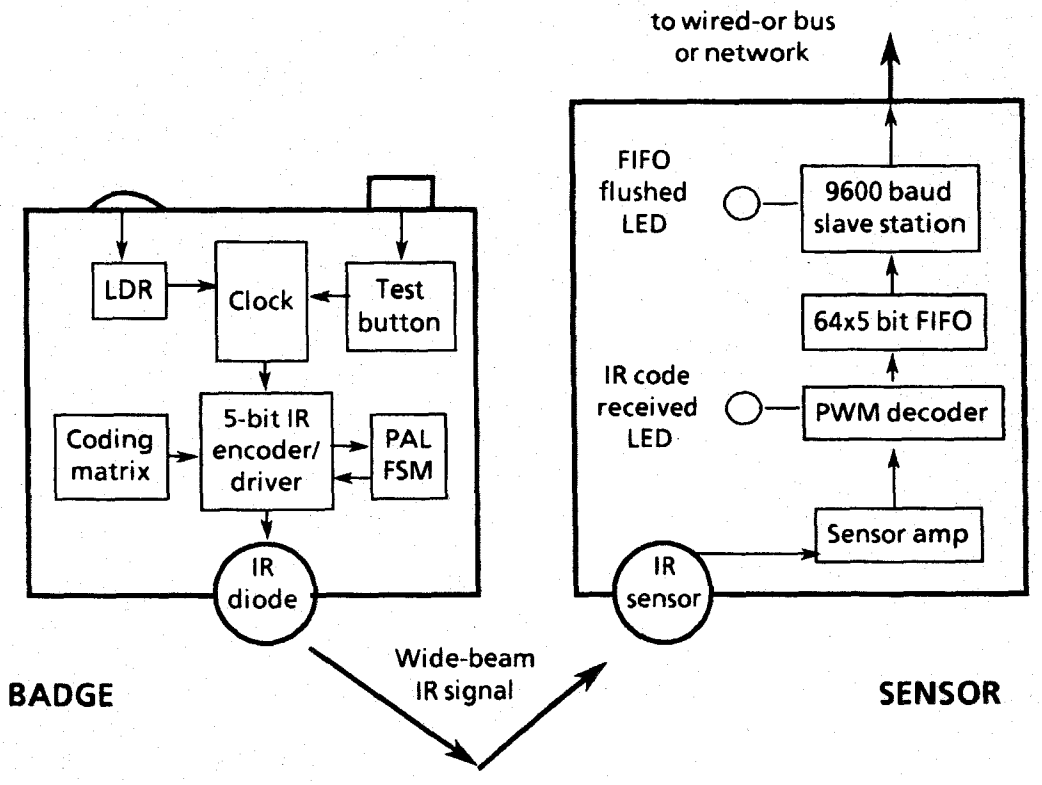

Fig 1. Active Badge Summary

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. The more obvious solution of a switch was rejected as it is likely that a badge user would sometimes forget to turn it on.

Other options considered for switching the device on included a tilt switch and an accelerometer although the size limitation of a badge precluded using these techniques in the initial experimental system.

2.2 Applications

The system provides a table of names against a dynamically updating field containing the nearest telephone extension and a description of the location. The format is such that it can be made available on all terminals and computers in the area and is shown in Figure 2.

The first column of the display (Name) indicates the name of the person. The second column (Telephone) indicates the telephone extension nearest their present position. The third column (Location) indicates the present location of the person and gives the room number and whose room it actually is. The next column (With) shows how many other people are nearby and thus gives an indication of whether the person may wish to be disturbed. The last column (Status) gives status information and an indication of movement.

The Status column is designed to indicate whether an attempt to contact somebody at the location concerned is likely to be worthwhile. Location information is given as a percentage and from an initial sighting, 20% is added for each additional sighting in one place. Thus after 5 consecutive sightings without change of location 100% is reached. It is possible to tell at a glance those people who are static (100%) and those who are moving (20% - 80%). After 3 minutes without a sighting the status field changes to a time (eg 12:30). Together with the location column this can show that a person has gone out of the building or has moved in some other way. If no sightings have been made for longer than a day the display indicates when the last sighting was made (eg Yesterday).

By pressing the single badge button one or more times the badge can be made to transmit. In this way a command can be sent by a badge carrier to the master processor. In the system in use in Cambridge this facility is used to provide a "Busy" function. This is indicated on the display screens by the word Busy in place of the telephone number and is cancelled automatically if the location of the wearer changes. This avoids the need to remember to undo the "Busy" setting. It can also be cancelled manually.

The Active Badge system has been deployed at a number of separate geographical sites. The sites exchange information and thus the location and telephone information can be kept up to date. Where the sighting is from a remote location the complete telephone number is given (eg University Computer Laboratory R76 in Figure 2). In the present system a user cannot control the distribution of sightings within his own organisation. However it is possible to control flow to and from other organisations.

If the links between sites have low delays there is no difference to service as seen by the user. Slow links (eg e-mail) can be used for widely separated places but the location information will be less accurate. Because time stamps are being passed round a more recent sighting takes precedence over older ones. Thus out of sequence packets and other network related problems can be dealt with easily.

In addition to providing display information the list of sightings is made available to programs. This allows simple investigations to be performed on the system. For example it is possible to list all the people in a particular room, sighted recently and so on. It also makes it possible for users to write simple text strings to the display (eg Away in Italy in Figure 2). Such strings have an associated display time and are automatically over-written by more recent sightings. A number of pictorial representations of the display information are also available.

The transmit-only active badge has proved very popular. A year after their introduction and with no requirement for compliance all employees continue to wear badges. Together with an installation at the University the user group size is about 150 persons. The overall effect has been to reduce the amount of time spent trying to telephone or look for others.

	Name	Telephone	Location	With	Status
P	Ainsworth	343	Accounts	0	100%
M	Chopping	410	R410 MC		Friday
D	Clarke	316	R316 DC		12:30
D	Garnett	218	R435 DG		12:20
T	Glauert	232	R310 TG	0	100%
S	Gotts	0	Reception	1	100%
D	Greaves	304	Floor 3 Corridor	0	40%
A	Hopper	334639	Univ Comp Lab R76	0	100%
A	Jackson	0	Reception	1	80%
A	Jones	210	Meeting Room	3	100%
T	King		Away in Italy		Monday
J	Martin	310	Machine Room		24 Dec
O	Mason	210	Meeting Room	3	100%
D	Milway	Busy	R211 DM	0	100%
J	Porter	398	Library	0	100%
C	Turner	307	Front Door		Yesterday
R	Want	308	R215 RW		09:35
M	Wilkes	210	Meeting Room	3	20%
S	Wray	204	R212 SW	0	100%

14:09 8 January 1991

Fig 2. Active Badge Display

3. TRANSPONDING AUTHENTICATED BADGE

3.1 Design

A successor to the original active badge has recently been produced and is called the Authenticated Badge (Fig. 3). The authenticated badge can receive and transmit, and has a battery life of up to one year. It has been slightly enhanced in terms of I/O facilities and has two buttons, two LED indicators and a tone generator to provide further user interaction. A small LCD display was considered but ruled out because the message would have been very cryptic. The number of buttons has been deliberately kept small to present a simple interface. The Authenticated Badge is a PiCO device that may be used as a combined location system, pager, and simple peripheral.

The Authenticated Badge was designed to enhance the security aspects of the original transmit-only badge by allowing it to accept a challenge signal, and to produce a response in return. A random component is used to make the challenge/response pair unique over a large number of challenges and periods of time. The response is generated by a one-way function operating on the challenge in combination with a secret password contained in the badge. This response is sent back with the unique badge ID. Because the original challenge is known it is possible to calculate independently the badge's response. If this matches the value the badge actually sent back then there is a high likelihood the badge is the authentic one. The whole system is protected from a bogus party replaying a recording of a previous badge challenge/response by the randomness of each

challenge and the security of the password contained in each badge. It would be extremely difficult for one badge to masquerade as another unless the internal password were somehow revealed.

Because of the necessity for low-power consumption, most of the time, the badge is in a low-power mode and cannot receive the challenge component of a challenge/response protocol. It can only listen for a challenge once every 15 seconds during a short period after its beacon signal. It is clearly undesirable to have to wait up to 15 seconds for some operations. As a result an additional detector has been added. This detector is sensitive to radio frequencies of about 150KHz. If a badge enters a field of this type it will automatically trigger. It can easily be arranged that such a field only has effect up to a specified distance (a few feet) and as a result a field generator can be fitted to secure doors and operate in the vicinity of workstations under the control of the badge network. If a button on an Authenticated Badge is pressed inside a proximity field, a challenge/response protocol will be initiated. This kind of event can be used to distinguish a button press outside of the field. If a room contains both a badge sensor and a workstation with its own badge sensor, then button presses that are directed towards the workstation can be identified. By using a

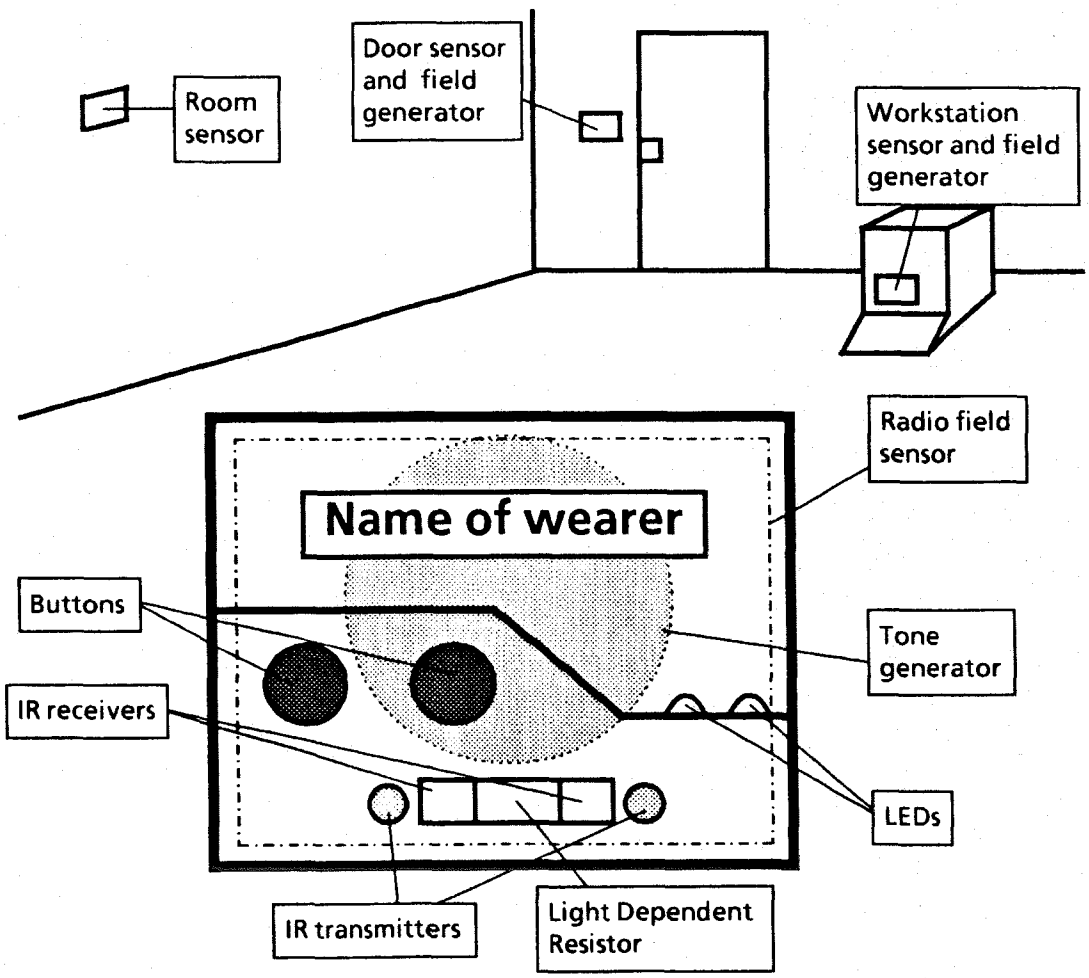

Fig 3 Authenticated Badge

combination of IR and radio the locating properties can be changed as required.

The Authenticated Badge uses a simple CPU for control and therefore its behaviour can be changed as required. It can be thought of as a very simple computer with duplex IR and simplex radio networks; and press buttons, LEDs and a beeper as peripherals. There is a danger that the extra functionality given to the badge will make the system complex for the user. However, it is believed that the context information makes the commands much easier to remember.

3.2 Applications

The Authenticated Badge can perform all the functions of the simpler Active Badge, but it can also be used in a number of new ways. It is important to note that the system is only secure while the Authenticated Badge is in the possession of its owner. If it is stolen the thief can masquerade as the owner. A PIN remembered by the badge owner would also be required, in the same way Bank Cash cards are used, if a high-level of security were required [5].

Authenticating badges have obvious uses for door entry systems. Secure areas may also require the sighting of an authenticated badge before entry is permitted. In both cases the authentication signals are produced in a way that does not require the wearer of the badge to do anything. A more continuous security check may also be performed by challenging the badge every time it produces its unique signal anywhere in the building.

The processes of logging onto a workstation can also be automated through a similar mechanism. While using a workstation the client may access a number of utilities, or domains of protection, each with its own security requirements. An authenticated badge would allow a user to be authenticated at several points during a session without needing to take any explicit action.

It is one of our goals to investigate the way a user can control the computer and communications environment. A more general way to think of this is as a script to specify rules under which different events should take place. Events in the computer environment can be communicated to the badge and the user can choose the way the badge indicates them. In turn, the movement of the user can create events in the computer environment which causes some state change. In addition to the usual telephone and workstation infrastructures, the Laboratory also possesses a video infrastructure. Figure 4 illustrates a model script which deals with workstation events, telephone events, video events and alarms.

Control of incoming events will be described first. Events to the workstation have been divided into incoming e-mail and others. When a piece of e-mail arrives for the user in this example a single beep is given out. More complex events (such as job-completed or visitor arrived), generate a triple beep and a workstation has to be consulted for details. Control of telephones by the user firstly requires routing calls to nearby handsets. When a call is routed in this way, an indicator on the badge will also come on. This means that when the user is with others (except in his own office) it is obvious that the call is for him when the phone rings. Secondly, because an automatic "Busy" system may be operating the user can choose to be informed when he has missed a call. In this case the user has asked for two beeps if this happens everywhere except his boss's office. It should be noted that control of portable telephones in this way is just as important as for fixed ones. Finally, the user has chosen to use a badge light to indicate when he is in the field of view of a camera. The alarm feature can be permanent and in the script for information only.

Outgoing events are divided into the same categories. The user has requested that the workstations in his office lock/unlock their screens when he passes through the door (whether they are portable or not). Automatic logon to other workstations is required as soon as he starts using one. For telephones, the script controls the "Busy" function. The user has asked that Busy is displayed on location screens when he is with more than 3 people, at a specified time (9:00 - 10:00 Mondays), at his present location if the badge button is pressed, and always when in the boss's office. Finally the user has requested a video recording to be made in his office when no badge wearer is present. A general help alarm facility is also available.

A number of features shown in the model script are already available. Some are proving popular but others are as yet proving difficult to incorporate in a simple way. It is encouraging that the popular applications have become

INCOMING

	Event	Location	Light	Beeps
Workstation				
	Incoming e-mail	All	No	1
	Consult workstation	All	No	3
Telephones				
	Incoming call	All	Yes	0
		My office	No	0
	Diverted call	All	Yes	2
		Boss's office	No	0
Video				
	In view of a camera	All	Yes	0
Alarm				
	Leave building	All	No	Continuous

OUTGOING

	Action	Location	Rule
Workstation			
	Lock/unlock screen	My office	Passing through door
	Logon	Other offices	When keyboard touched
Telephones			
	Busy	All	With more than 3 people
		All	9:00 -10:00 Mondays
		Present location	When button pressed
		Boss's office	Always
Video			
	Record	My office	No badge present
Alarm			
	Signal help	All	Button pressed 3 times

Fig 4 Personal Control Script

established quickly and users do not wish to go back to an environment without them.

4. DIFFERENT TYPES OF PiCO

Today's laptop computers and the growing number of products described as Palmtops, Personal Electronic Diaries and Smart Tags are examples of PiCOs [6]. All of these have limited stand-alone use in practice but, if attached to a communications link can provide direct access to more complex computer systems. Figure 5 illustrates some applications for PiCOs working at a variety of communications speeds. The first portable device was the *laptop*, which generally has a keyboard attached to it. However PiCOs are much lighter. The smallest is a *personal active badge* of the type described earlier. It has extremely limited input and output facilities. An *active minipad* contains a small display and has some form of input. It is lightweight and may be

carried in the same way as a wallet. To display documents and graphics, a *touch-sensitive tablet* would have to have a larger format. This is less likely to be carried by the user at all times, but if it is sufficiently low cost, then large numbers can be provided (like telephones).

The networking axis in Figure 5 spans the range 9.6Kbps to 10Mbps. For the time being higher speeds will not be easily attainable for personal devices because of high power consumption. There is .an overlap between the speed capabilities of infra-red and radio, the main difference being that infra-red can be controlled in the physical domain while radio penetrates most physical objects. These properties can be used to advantage to construct cellular communications systems whose cells have specified properties. In general, infra-red cells can be mapped onto the working space of individuals or groups while radio can be used where more systematic coverage is required. The communications path from the portable device to a base station is normally just one part of a more comprehensive communications infrastructure based on a high speed wire or fibre backbone.

Figure 5 shows the points at which different facilities first become feasible. Thus paging or location are possible with very low bandwidths to the portable device. A number of further applications follow if a lower speed link is available, such as simple display facilities. As the speed of the link increases it is possible to use more sophisticated I/O technology. This can include touch-sensitive input, which at slow link speeds can be used to select options presented on the screen. Such choices can be made more rapidly if the down link from the base unit is faster (using more power) than the return link. If the up link is fast enough, then continuous writing can be transmitted to the base unit. Further bandwidth allows audio I/O and possibly video I/O. As the network speed increases the computation model can change to allow the device to act less as a stand-alone computer and more as a

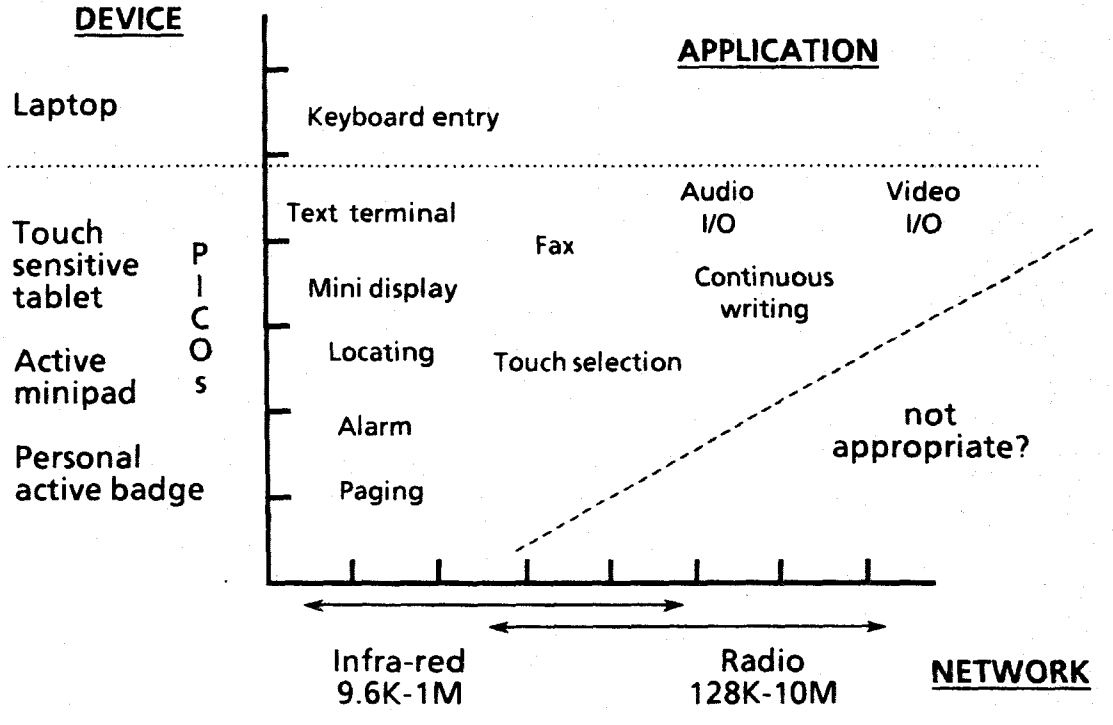

Figure 5. The multimedia space.

terminal with remote fixed machines performing the bulk of computing. This means the portable device can be made lighter, although the penalty for loss of contact with other systems can be a considerable degradation in service.

5. POSSIBLE USE OF PiCOs

It is interesting to speculate about the usefulness of applications which use PiCOs. A single hardware design can be used in many ways. In general complexity should be avoided. PiCOs should need very little tuition to use them and most of the properties of the devices should be clear from their use.

It is assumed that PiCOs will at least have a location capability. Generation of location information only needs low speed networking. The type of location information available may vary according to whether it is being supplied by a badge, a minipad or a tablet. The location information may relate directly to where an object is (eg tablets may know where they all are) or it may relate to individuals (as with active badges). If higher speed networks are available the applications can handle more complex forms of data such as facsimile, audio and video.

A device can automatically invoke an interface specified by the user in front of it. This interface can be aware of what PiCOs are in the vicinity and thus for example display status and error information in the most convenient way. The exact effect of interaction with a PiCO can be defined by a profile edited within the usual workstation environment. It is here that these commands can be bound to the various command signals with the appropriate context attributes. Almost any device could benefit from this facility: from the station buttons of a radio and the default settings of a photocopier to buttons and command interfaces for software systems. Suggestions for potential context sensitive applications are given below.

5.1 Control of workstations and computer systems

System management
There are many tasks for which the computing environment is responsible. A typical example is printing documents and running processes based on users' requests. All these tasks require job queues to be maintained and it is clear that the importance of carrying out a particular task may be related to the location of the person who initiated the task. For instance, rather than specifying the name of a printer, it may be simpler to walk up to any printer and have the output delivered there. It may also be fairer to run computational jobs at a higher priority for users that are still in the building than for those who are not (for example paging out their jobs to disk). In this way the system may adapt its usual naive operation to be more receptive to the needs of the environment it is used in.

Electronic Mail
A workstation can use a PiCO to provide a more effective interface. The system may become aware of the first sighting of a user on a particular day and can automatically configure itself to read the mail boxes. If a visitor appears from another site it would be possible to poll the remote site for mail at that moment rather than wait for the polling algorithm to be activated (e.g once per day). If a minipad or tablet is available the mail can be shown by displaying a part or the whole message.

Voice Recognition Systems
The best results to date are achieved by voice recognition systems that have been trained to particular voices [7]. A transmitting PiCO allows a voice recognition system to determine the identity of the person using the system and therefore the correct parameters can be set up automatically to optimise the recognition of their speech.

Online Diaries
The diary can indicate meetings and when and why people are away. Such information can be inserted manually or derived automatically from sightings and be made available on PiCOs with a display. More recent sightings override the diary information and thus if the person concerned returns early or later than in the diary the display will automatically reflect the real situation. Location information could be used to associate people and places. The diary can be used to warn a user who has a meeting scheduled but is in the wrong place. A user looking for a meeting could be told where there are groups of people.

Information Retrieval
A modern trend for computer systems is to support multimedia applications [8]. A

proliferation of workstations, each with their own camera and microphone, may be commonplace in the future. Automatic information about who is in front of the camera (or in the same room) would help in the management of such systems. The concept of digital video and audio stored in huge chunks presents a difficult task for people trying to locate specific stored events. Unless the information can be stored with attributes that may be used to locate these events, the search using pattern recognition techniques would be lengthy and difficult to do. An Active Badge provides an automatic method of tagging video with information about the people (and things) that are currently being filmed and these attributes can be scanned by conventional search facilities.

5.2 Control of telephones

Telephone Handsets
It is often possible to program frequently used telephone numbers into telephone handsets as "short codes" which are convenient for rapid dialling. The problem is that the short codes vary from one telephone to another. The transmitting PiCO provides the opportunity of having relatively simple telephone handsets connected to a central PBX but using the location information to interpret the short codes in different ways depending on the person making the call. In other words the properties of any phone which a PiCO wearer approaches would be the same. By allowing users to define their own key sequences to trigger PBX features, they may be remembered more easily.

Telephone Calls
A PiCO with a display can be used to show information pertinent to telephone calls. Furthermore telephone calls in an integrated service network could also be automatically transferred to the telephone extension nearest the person for whom they were intended. This mechanism could also be qualified by many constraints concerning time, the office you are in, the people you are with, and, if modern ISDN features are available, who is calling.

5.3 General

Security
Physical security systems based on passive infra-red sensors are often used to warn of movement in areas that should have no intruders. A location system allows a refinement of this information to permit movement in the presence of badge holders but to warn of a possible alarm otherwise.

Integrated Building Services
A modern building has many electronic systems that need to be controlled but which are functionally separate. These systems include lighting, heating, air-conditioning, security, smoke detection and lift control. It may be desirable to control some or all of these systems by taking advantage of information supplied by PiCOs.

6. CONCLUSION

Active Badges are the first of a family of PiCOs. An Active Badge can be attached to an individual or object. A number of experimental systems which use badges are in use. Preliminary results indicate that such systems make it possible to communicate more efficiently with others and to present an easier to use interface to complex systems.

A facility which an Active Badge provides to computer systems is location information about users and objects. An Authenticated Badge can be used to minimise the likelihood of intrusion. By using a control script the location information can be used to trigger events in the computer and communications environment.

Different types of location information can be provided. This can be coarse grained information between buildings, more accurate within buildings, within a few centimetres in an office, and to a fraction of a millimetre on the surface of a tablet. PiCO devices with a combination of computing, communications and location properties will have subtle effects on our interaction with other individuals and computers.

Active badges and other PiCOs that can transmit and receive, integrate well into the computing environment. One way to view them is as portable terminals which contain independent computational power. There is a tension between the use of local computational power and delegation to remote servers. Using local power allows the device to continue working after loss of communication but the use of shared applications is made difficult. Using remote computing power allows both shared and more complex applications, but is vulnerable to loss of communications. A duplex PiCO can make

decisions about how much of a command should be processed locally or processed remotely. As technology develops it will be possible to run more complex algorithms in the portable device which blur the distinction between "in-contact" and "out-of-contact" operation.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

[1] R. Want, A. Hopper, V. Falcao and J. Gibbons, "The Active Badge Location System", ACM Trans. on Information Systems, Jan 1992.

[2] S. L. Harper, R. S. Worsley, and B. A. Stephens, "An Infra-red Link for Low-Cost Calculators and Printers", Hewlett-Packard Journal, October 1987.

[3] A. Paepcke, R. D. Crawford, R. Jamp, C. A. Freeman and F. J. Lee, "Chipnet: An Optical Network of Terminals and Workstations", Elsevier Science Publishers B. V. (North-Holland), Computer and ISDN Systems, 15, (1988), pp.203-215.

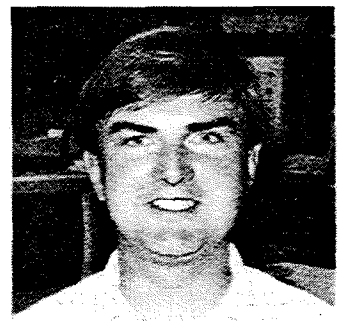
[4] Satellite, Cable and TV IC Handbook, Plessey Semiconductors, 1988, pp. 64, 67, 124.

[5] "Computers at Risk", National Academy Press, 1991, pp. 98.

[6] P. Hewkin, "Smart Tags - the distributed memory revolution", IEE Review, June 1989.

[7] Doddington and Schalk, "Speech Recognition: Turning Theory Into Practice", IEEE Spectrum, Sept. 1981, pp. 26-32.

[8] W.F. Leung, T.J. Baumgartner, Y.H. Hwang, M.J. Morgan, and S. Tu, "A Software Architecture for Workstations Supporting Multimedia Conferencing in Packet Switching Networks", IEEE J. on Sel. Areas in Comms., Vol. 8, No. 3, April 1990.



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