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Smart Homes

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Introduction

The basis of smart home technology is the use of sensors in the home that can monitor the behaviour of the occupant and their interaction with their environment, and to use this information to enable assistance to be provided. The technology has really come into its own in recent years as concern has grown about the impact of the rapidly ageing population on the provision of health and social care. The technology has the potential for supporting the lower level needs of residents without expensive human intervention from professional carers.

In the early days of the use of intelligent homes there was some concern that this technology would have the effect of reducing if not replacing the support of human carers. Professional carers in particular were concerned that this apparent technology-fix was being driven by the health economics of caring for vulnerable people, and were extremely concerned that the complex interactions and sensitive understanding that are part of direct human care would be lost. It took some time, and indeed some successful experience of the ways in which technologies installed in the home could augment the support of human carers, before this view changed to one of seeing these new technologies as just one tool amongst many others that carers can use to support vulnerable people at home. It also became apparent that some of the more autonomous technologies actually had major benefits for their users over direct human support because they provided users with increased self-reliance and a degree of control over their lives that had a major impact on their sense of well being.

There has long been an interest in remote control technologies that enable people with a wide range of disabilities to interact with their environment more easily. The use of environmental control systems in particular have enabled disabled people who have mobility problems, or have difficulties manipulating objects, to have some control of their living environment. Such environmental control systems enable the user, often from their wheelchair, to have remote control of domestic appliances, or to open and close the curtains, or to respond to visitors at the door, etc. The control is effected by means of remote controls using infra-red or radio-frequency communication. The technology is described in detail in the article on environmental control systems.

This article will focus on the use of sensing technologies that can remotely monitor people in their living environments and generate responses accordingly. It will examine the kinds of smart homes currently in use, from telecare to more autonomous installations. It will look at the ways that this technology can emulate the support that can be provided by live-in carers, and highlight some of the issues currently being researched.

Telecare Support Technology

Basic technology

The early use of smart homes involved telecare support technology. There are many commercial companies selling and supporting telecare and it has become widespread in many countries, and the technologies involved have reached a high level of maturity. There is a growing body of evidence concerning its impact on people's lives (eg, Woolham 2006). The technology spawned from the use of community alarm systems. These involve the use of a body-worn alarm button, usually in the form of a necklace pendant. If the user requires some assistance, following a fall for example, they can press the button on the pendant. This action activates a receiver on a modified telephone which can then automatically contact a call centre. The call centre operator can then check with the user that the call is genuine rather than a mistake, and if assistance is needed they can contact someone to go around and provide help. Telecare is a natural extension of these communication technologies. Instead of using the pendant to contact a call centre a series of sensors in the home can do this automatically. The sensors are designed to detect situations where there might be danger for the user, for example by detecting the occupant going outside in the middle of the night, or the forces generated as the user hits the floor following a fall, or more sophisticated events such as a flooded bathroom. In the event of any such occurrences the call centre will be contacted. The staff there will know what has triggered the call and can respond by initially speaking to the occupant, and then sending someone around to provide assistance if it is needed.

The benefits it provides

The automated monitoring and responding of telecare systems provides peace of mind to families that a check is being kept on their loved one, and if any one of a number of dangerous occurrences arises then this will be detected and help will be provided. The user also has the reassurance of knowing that they will be helped if such occurrences arise. Evaluations of this technology have shown that it provides good support for its users (Waddington and Downs 2005), and indeed in more than one case had been a key factor in preventing major injury. The major impact has been through using the more straightforward sensors such as door sensors and movement sensors. Sensors designed to detect more complex behaviours such forgetting about running baths and flooding bathrooms, and misuse of cookers, were found to be less effective. It has proved to be quite difficult to detect complex human behaviour from the use of simple sensors, and some applications such as detecting misuse of bath taps clearly requires quicker responses than can be provided through the convoluted response route via call centres to someone visiting to provide help. The people being supported by telecare installations are mostly frail elderly people in their own homes, but work has also been carried out to explore the application of the technology to more severely disabled groups, such as the pioneering work carried out in Norway to support people with dementia (Bjoerneby 1997).

There are potential cost savings for health and social care providers using telecare because there is not the same need for regular checks by domiciliary staff, and helping someone to stay independent in their own home rather than going into care could save large sums indeed. Also the detection of some behavioural situations, such as going outside in the middle of the night, could reduce healthcare costs as the more severe outcomes of such actions would be reduced.

A clear limitation of telecare installations is the need to involve call centres in the response loop. The call centre staff can provide some remote verbal support but if help is required then they have to contact people on their lists to pay a visit and resolve whatever problem had arisen, with an inevitable delay whilst this takes place. More subtly for the user these systems are basically just monitoring their behaviour. They can send help if it is judged necessary but cannot enable the users themselves to deal with problems, and in that sense they are not very empowering.

Autonomous Homes

What are autonomous smart homes?

Smart home technology really comes into its own when the response to the sensor information is provided directly by the installation. Such autonomous installations can much more closely emulate the support provided by a live-in carer. These installations have three basic components. Firstly they employ a range of sensors installed in the home that can monitor the behaviour of the occupant and their interaction with household appliances. Secondly they include support devices that can carry out the kind of actions that a live-in carer might perform, such as turning lights on or turning off the cooker. Thirdly they have a communication network that links all the sensors and support devices together. The network has embedded computational capabilities which enable it to apply algorithms that use the sensor data to make a judgement about how to respond. If it decides that help is needed then it can activate appropriate support devices. It only needs to call for assistance outside the home in the event of an emergency. This call for assistance can be to call centres, but it can also be via automated phone calls to neighbours, sms messages, etc.

The basic technology

The core technology required by these installations has been commercially available for some years to provide autonomy of environmental control in large public buildings such as hotels and airports. A large number of sensors and actuators are available, and the network technology had matured to a high level. The more sophisticated networks such as the European Installation Bus/KNX and LonWorks have in-built checks to ensure communication between its various components. Such systems therefore demonstrate a high level of reliability, something important for the support of vulnerable people in their homes. Most of the current installations in public buildings also used hard wired networks, again to maintain reliability, and also because most would be built into new constructions where the wiring could easily be hidden. For installations in people’s homes such extra wiring clearly causes complications. The installation is likely to be a retrofit, and because the wiring has to be routed between rooms there is a major disruption to life that can be quite unsettling to the kind of frail old people whom it is hoped might benefit. Networks that use radio frequency (RF) communication to provide the links between its components have clear advantages. Installations can be much more plug-and-play, and much less disruptive for the user. However there is always the problem of radio dead spots that can occur with RF links. In addition the sensors and support systems are likely to require a power supply, which for hard wired networks can easily be provided by the network itself, but for RF networks require an additional mains connection or the use of batteries. Fortunately for most sensors the power requirements are very small and batteries can last many months, and they can signal their need for replacement. Of course RF communication has become a major part of the design of portable appliances and the technology has become very efficient in use of power. There is also much interest in power scavenging systems that can use the fact that there is some human intervention to generate low levels of power. For example the operation of a light switch can be used to generate minute amounts of power but this can be sufficient for its communication needs within an RF based network. A further technique to hard-wired or RF systems uses communication via the mains wiring by superimposing the sensor information and control signals onto the mains waveform.

The support provided by autonomous homes

How can this automated technology be used to support people in their own home? The technology has the role of emulating the support provided by a live-in carer. A live-in carer can watch and monitor the behaviour of the person they are caring for, and can detect when someone requires support. They can then make a judgement about the kind of support that can be provided. The same actions can be taken by an autonomous installation. A good example is the pioneering study of the use of such technology that took place in the Edinvar scheme in Edinburgh in Scotland. Good support was provided at night through the use of two simple sensors. These were movement sensors (Passive Infrared Sensors, or PIRs, similar to those used for burglar alarms), and bed occupancy sensors (this installation just used a pressure mat by the bed to detect when someone got out of bed). If the occupant got out of bed at night and the room was in the dark, the installation could make a judgement that lighting was needed and that the user may well be wanting to go to the toilet. Low level bedroom lighting could be automatically turned on, but also the toilet lights could be turned on to guide the occupant to the toilet. When they had finished in the toilet, movement sensors would detect their coming out of the bathroom, the toilets lights could be turned off and the bedroom lights could be turned full on to guide the user back to bed. These installations were carrying out simple detection and response in the same way as if the occupant were living with a caring spouse who was helping during the night.

What sensors and support devices are in use?

The PIR sensors described above are universally used to detect movement around a dwelling, and the presence of the occupant in different rooms. They are simple and reliable, and can be arranged with shielding to provide a kind of detection curtain. Such sensors near an exit door for example can be set up so they are only triggered if the occupant moves close to the door, as they would if they were about to go outside. If there is a pet in the home it is useful to set the sensors up so that they are only activated by the human occupants and not a pet near ground level. Bed occupancy sensors have used a variety of designs. A simple technique is to use pressure pads next to the bed, as mentioned in the example above. However it is quite easy for the occupant to miss the pad when they stand up next to the bed. Some use a sensor in the bed, mostly above the mattress, which senses the presence of the occupant in bed. Some are positioned under the bed legs and monitor the weight of the bed to detect whether someone is in or out. Door sensors, as used in burglar alarms, can usefully signal when someone has opened a door, particularly useful for occupants who are prone to go outside during the night because of confusion about the time. Some sensors have been designed to detect dangerous behaviour. For example, sensors can detect when gas from a cooker has not been ignited, or if something is burning near the cooker. Others can detect when a bath is full or has over-flown and is flooding the bathroom. Background information is also useful for the network computer to enable it to make appropriate judgements. Time is of course important, not just to know what time of day it is, but also to monitor how long someone might be carrying out an action like wandering around the house at night, or watching TV. Light level sensors can let the installation know if the occupant needs extra lighting. Many other sensors have been used such as radio-frequency identification (RFID) tags, accelerometers for fall detection, etc. These basic sensors can provide the bulk of the information needed to enable support devices to be used effectively, but several other more specific sensors have been designed.

Support equipment can be as simple as automatic turning on of lighting. As described above, such actions can be used to provide guidance within the home. More sophisticated devices can be used to turn off appliances such as the cooker or the taps used in the bath or kitchen sink. Some can provide an element of time orientation through reminding about the time of day (morning, afternoon, time for a favourite TV programme, etc) as well as the actual time. These can be extended to provide information about the date as well, and reminders about appointments such as for the doctor. Such reminders constitute an important set of support equipment that can also include voice prompts. These have been particularly effective for people with poor memory or a cognitive problem, as discussed below.

Installations

Much of the technology discussed in relation to autonomous homes is in the research stage, although at quite an advanced level of development. This situation is likely to change quite quickly, although there are obstacles to the simple introduction of such technologies. The installations have most benefit when they are tailored to the lifestyle and needs of a given individual. They also require some links to outside the home to deal with emergencies and to enable care professionals to monitor the occupant's well being. They also require a fast-reacting technical support. This clinical and technical infra-structure is not generally available in most countries and would be needed to be established to work alongside any new commercial products in the form of installations.

The one country that has moved these kinds of installations forward into mainstream provision is Holland. Their Smart Home project has several thousand homes fitted with basic autonomous installations (Bierhoff et al. 2007). The KNX communication network is employed together with a fairly standard set of sensors and support equipment. Installations include automatic lighting and outside door monitoring. A useful feature of these installations is a central locking facility which can lock all doors and windows remotely. These homes are mostly fairly standard installations and not tailored to the needs of the individual, although this is something that clearly could simply be developed now that large scale installations are available. The authorities in Holland have just started applying the technology to supporting people with dementia and this will inevitable mean they will have to fine tune the installations to the needs of their individual clients.

Configuring Installations to Provide Support

Emulating carers

The key issue for these autonomous home installations, and the one that provides them with intelligence, is how the sensor information is interpreted to provide support, and the way the installation is configured to best support the individual. A useful example of how installations can be configured to support an individual is the work carried out as part of the Gloucester Smart House in the UK (Orpwood et al. 2005). The technology was specifically being employed to support people with a mild to moderate dementia. This work was guided by a survey of personal carers to hear from them the problems they had to deal with and to listen to the kind of strategies they had found worked for them. It was felt that the strategies employed by personal carers would give good guidance about how to configure installations.

A key problem for the occupants was one of their forgetfulness. They would often initiate actions in the home such as boiling a kettle and then forget all about it. Surveys of carers showed that in these situations the carers would typically follow a four-stage response. First of all they would monitor the occupant and note when potential problems had arisen. Secondly they would initially provide a verbal reminder to the user such as "Don't forget, you've got the kettle on". Thirdly, if the user took no action, the carer would intervene to resolve the situation, such as turning off the kettle when it had boiled. And then fourthly they would reassure the user that the situation had been resolved, such as telling them, "The kettle boiled, and I've turned it off for you". Note that in following these actions the carer is supporting the user but not taking over control of their actions. They try to prompt the user to deal with the situation himself, and only intervene when necessary.

The simple sensors and support technologies described above can be configured to emulate these actions. If the user was running a bath and forgot about it, the technology could monitor the situation through tap sensors and movement sensors. The tap sensors would provide information that they had been turned on, and the movement sensors would detect that the user had gone out of the bathroom, thereby emulating the first of the carer's responses. Secondly, through the use of voice prompts, the installation could then remind the user about their actions and the need for a response. Thirdly if the user didn't respond, one of the support devices could be activated, in this case automatic taps that turn themselves off. Before it did this it would need to wait until it knew the bath was quite full, and in this case another sensor would be needed to detect the water level in the bath. And fourthly, once the taps had been tuned off, a further voice message could be provided to reassure the user that everything had been taken care of. None of this sequence of events requires anything particularly sophisticated in terms of the sensors used. Most are already commercially available. The support device requires a tap that can be turned off without human intervention, but again this is not requiring a particularly sophisticated technology. The end result is a configuration that uses simple sensors and support devices to provide similar kinds of quite sophisticated support to that provided by a live-in carer.

Voice prompts and reminders

Most human interaction requires verbal communication. The project described above found voice prompts were a key part of supporting someone in a similar manner to a carer. It was found that a voice of a person they trusted to give them good advice was the most effective in influencing their behaviour. It was also found that occupants quite accepted the voice prompts, and even for people with dementia they did not confuse the disembodied voice with someone being in their dwelling. Using a familiar voice requires recording messages that can be used in the installation. It was found best to ask the family member being recorded to imagine they were standing next to the person they were caring for and to provide their message as though they were talking to them, rather than using a stilted, answer-phone, kind of message. This process worked really well because the carer knew the person well and knew the kind of tone of voice and way of talking that would be most effective in influencing their behaviour. Some studies have shown evidence of habituation when using recorded messages such as these and means for regularly changing them have been indicated as being necessary.

Some work has also been carried out to see if the user's voice can be recognised so that two-way communication is possible. A pioneering project employing this approach was the Millenium homes work carried out by the Brunel Institute of Bioengineering in the UK. If the sensors indicated that the user was in need of some assistance the installation would first of all ask the occupant if they needed this help. It could recognise the occupant's response through simple voice recognition software. Voice recognition of course suffers from the problems of needing learning on the part of the software, and that in situations of stress the user's voice can alter. Nevertheless such software is becoming quite a mature technology and will clearly have an increasing role in these installations. The fall detection system developed in the Department of Occupational Science and Occupational Therapy at the University of Toronto used voice recognition to good effect to allow a variable response from the faller so that they can signal when they needed some assistance (Hamill et al. 2009).

Design of support devices

Support devices also need to operate in a way that can emulate the actions of a carer. With the automatic tap example discussed above, it would have been quite a simple matter to have installed a water shut-off valve in the supply to the tap, and if the installation judged it was time to turn off the water supply, it could just cut off the water. However, if the user subsequently tried to run in a little more hot water, or if they came back the next day having emptied the first bath, they would find the taps didn't work because of the shut-down water supply. Consequently a tap was designed that behaved as though a carer had turned it off. A shaft was connected to the tap handle which operated an encoder to detect how far the tap had been opened, and a flow control valve was opened accordingly. If the water had to be shut down, the flow valve was turned off, the encoder was reset, and an electromagnetic brake was applied to the shaft to make it feel as though it was turned off. As far as the user was concerned the tap felt as though someone had turned it off, and if they tried to turn the tap on again the encoder would be activated and the tap would operate as usual. The end result was one of quite closely following what a live-in carer would do in this problem situation. So the analysis of the behaviour of carers is important in guiding the more detailed design of the support equipment.

Sensors can sometimes do better than human monitors!

Despite their simplicity, the kind of sensors described can be very effective in providing an insight into the problems faced by occupants. A good example of this is an autonomous smart home that was set up in London in the UK (Orpwood et al. 2008). The user was a man with quite a well developed dementia (MMSE score of 10) who had a continence problem and who tended to wander at night. His sensors were used for a month without turning on any of the support technology. This was done to provide a baseline control to enable the impact of the support technology to be assessed. During this control period his bed-occupancy sensors indicated that he was getting very little sleep. He was in and out of bed all night and averaged around 3.5 hours a night. His movement sensors also showed signs of confusion within his apartment, as he moved from room to room before he found the toilet. None of this behaviour had been clear to his human carers. Consequently when the support technology was turned on, it was configured to try and help with both the sleep and toileting issues. If he got out of bed the bedroom light would be turned on (faded up) and also the toilet light. His daughter's voice would remind him about the toilet and that its light had also been turned on. This helped the occupant to find the toilet and reminded him about going. When he came out of the toilet he would tend to wander around the apartment. Initially no action would be taken, but if this continued for more than ten minutes his daughter's voice would remind him it was night-time and suggested he should go back to bed. If he went back to bed but forgot to turn off the light this would be done for him after a short delay. If he carried on wandering for some time though the night staff in the care home would be contacted to go and see him to check he was okay. The end result of this intervention was that his sleep increased to around six hours a night, and he became completely continent. The configuring of the installation in order to tailor it to his needs was a simple matter but it had a profound impact on his life.

Night-time wandering

Night-time wandering is an important behaviour for people with dementia that causes a lot of concern and can be very dangerous. This behaviour needs to be understood more clearly for a given person to understand what is motivating them, but autonomous home technology can provide help. It is relatively easy to detect that someone is about to go outside by using PIR sensors near the door in the manner described above. If movements are detected near the door during the night, then the installation is able to judge that the occupant is likely to be going out. Voice prompts have been quite effective in these situations to discourage going out, again particularly if a trusted voice is used. If the occupant does go out, then door sensors can detect the door opening. This situation is one of the main ones where the installation has to contact outside help. This could be to a call centre, but it could also be to a neighbour or a relative who lives near by. Other technologies have an important role here (such as GPS positioning or mobile phone triangulation) to track where the person has gone so that they can be contacted and given some care.

Cooker support

Misuse of cookers in particular is often a key factor in deciding to move someone into care to prevent them causing injury to themselves and to ensure they eat properly. Quite often cookers are disconnected and the occupant is provided with a microwave, but if they haven't been used to using one for cooking they are unlikely to learn to rely on it. Misuse could be through putting pans or kettles on and forgetting all about them, forgetting to light gas, burning food, putting plastic kettles on a cooker, contact with cooker hot plates that had not yet cooled down once they have been turned off, etc. Various sensors have been developed to try to provide support for cooker usage. Food that is burning can be detected with smoke sensors, and these sensors can also detect when fat has been overheated and is generating a lot of fat “smoke”. They are also useful for detecting when a pan has boiled dry and the food is charring, although it can take a long time to reach this state. Heat sensors have also been used to detect similar situations to the ones above. Raw gas sensors are very effective in detecting when gas has not been lit. Some work has been demonstrated using infra-red heat sensors that sense the outside temperature of pans and kettles and can signal when they have boiled dry. Similar infra–red sensors have been used to detect when hot plates are still dangerously hot, and can warn the occupant. As with the bathroom taps the initial response from a cooker support system could be a prompt to take some action like ensuring the gas is lit or checking a kettle hadn’t boiled. The installation can also provide an intervention in the same way as a carer, and this usually means turning off the gas through a gas control valve or turning off the electricity if an electric cooker is being used. And, of course, a reassuring voice message can be used once some action has been taken. If the gas or electricity supply to the cooker is shut down, then someone has to turn it on again after checking that the cooker knobs are all off. This requirement, and the potential of fire or serious burns from cookers, means that if danger is detected in the cooker environment, then this is another situation where the installation has to call for help from outside the home. So cooker support usually requires a two-stage response. The occupant will initially be prompted to take action. If they do not respond, then the installation will turn off the gas or electricity and call for help.

Processing sensor data

Judging complex human behaviour

At the core of the operation of autonomous smart homes is a need to make judgements about human behaviour. These are usually trivial judgements on the part of a human carer but are actually very difficult to do reliably using simple sensors. Human behaviour is complex and variable, and making decisions about that behaviour can be very difficult. The system mentioned above to detect pans boiling dry is a useful example to illustrate this point. The system used infra-red sensors that were pointed at individual pans and monitored their surface temperature. This temperature remained fairly constant during most usage but if the pan had boiled dry the temperature would suddenly increase. This increase could be easily noted from the sensor data and action initiated. However the sudden increase in temperature could also be caused by other behaviours on the part of the user. The occupant could turn the gas up and down whilst cooking. They could move the pan between different rings. They could misalign the pan so that the gas flame came up the outside of the pan. These are all quite typical actions during cooking but they could all cause sensor measurements that suddenly change and seem to imply that the pan had boiled dry. The algorithms that were developed for this sensor could correctly detect pans that had boiled dry about 85% of the time. This is of course nowhere near reliable enough in a safety critical situation like cooker usage. The system could be designed to tend to respond to false positives but this can cause a lot of annoyance on the part of the user if their cooker keeps turning off when it doesn’t really need to. Careful thought about back-ups and the alerting of third parties is crucial for the configuring of these systems. Although this example relates to a particular problem of detecting pans that had boiled dry, the point being made is a general one. Making clear-cut decisions about human behaviour is complex and very difficult to do using simple sensors. The sensors can only provide a probabilistic response rather than a clear yes/no message.

Indirect judgements of behaviour

Making judgements about behaviour has led to a number of interesting indirect monitoring systems. One study found that the use of the fridge was a key indicator of people feeding properly. If the fridge door had not been opened for some time it was felt that this was a clear indication that they weren't eating well. However this is clearly an indirect indication of behaviour, and again is just providing probabilistic indications. Someone may well be eating quite properly but just not require fridge access for a couple of days. They may be using the fridge frequently but because of their dementia they might be simply putting toilet rolls in it by mistake. The use of such sensor data becomes more useful when combined with adaptive data processing so that changes over time from a regular behaviour can be detected. Other indirect sensors include monitoring the usage of domestic appliances such as the TV. The use of the TV may well indicate that the occupant is engaged, and if a regular pattern of behaviour is detected then any changes from this would suggest some human intervention would be required. Usage of such appliances can simply be monitored through the use of mains power detectors built into a plug adapter.

Data interpretation

The kinds of installations discussed generate very large amounts of data. This data is of course essential for making decisions about interventions to help the user, but it is also very useful for providing carers with an indication about how the occupant is getting on. The example mentioned above of helping someone improve their sleep was a case in point. It was only because of the bed occupancy sensor data that care staff realised that he was getting such a small amount of sleep. The information the sensors can provide is therefore extremely useful for professional carers to be able to ensure the occupant is getting appropriate support. It is also very useful for the occupant's family to be provided with some reassurance about how the person is getting on. The commercial sensor system "Just Checking" is a successful and very simple system that just monitors movements and relays to data to a secure website for carers.

The raw sensor data is very detailed and requires translation if it is to be useful to carers. Some work has been completed in this area. The main approach has been one of providing lifestyle monitoring using the various movement and other sensors in order to try and detect "typical" patterns of activity. The aim is to use this kind of statistical data to enable variations outside of the norm to be detected, and for this to be used to alert care staff. It has been found, however, that the data is so variable that it is difficult to define what is normal behaviour for a given individual (Hanson et al. 2007). The need for care staff to have some sense of how users are getting on does mean that some form of alerting is needed because the professional carers clearly cannot be monitoring a large number of users all the time. They need to know when the occupant requires some intervention and help. This is an active area of current research.

Future developments

More than one occupant

One of the key limitations for the kind of autonomous homes described is that they ideally require the occupant to be living on their own. The sensors described cannot distinguish between different occupants so in some situations if there were more than one occupant the judgement being made about how to intervene would be severely compromised. In order to distinguish between two occupants some means of identifying the users is needed. At present this can only easily be done with body-worn labels of some sort, such as Radio Frequency Identification (RFID) tags, although video data processing has been successfully used in some applications. The advantage of two occupants, other than the obvious social benefits, is that the live-in carer can be part of the response of the installation. They could be alerted if the cooker had just been turned off because of the behaviour of the disabled occupant, and can respond immediately in providing support rather than waiting for a neighbour or for care staff.

Adaptive homes

A further stage of sophistication for intelligent homes is to provide them with some learning capability. Just as a live-in carer would learn to know the behaviour and habits of an occupant, an installation could do the same and thereby provide a more personal support. Such adaptive capabilities would be extremely useful if these technologies were to be rolled out on a large scale. Rather than care professionals having to monitor people's behaviours closely and fine-tune installations to their needs, the installation itself could adapt according to the user's particular needs. This would make the installation and running costs of such systems much cheaper and it would also mean they would be far more effective in the support they were providing. There would also be advantages for people living with a deteriorating condition such as dementia. As their abilities changed, the installation would change with them, and provide an increasing level of support.

Some work has been completed in this area. Some aspects of people's behaviour can be learnt quite quickly. For example, a key variable that needs to be included in most installations is what constitute bed time for the individual. This is required in order to know when to discourage them from going outside. It is also important in more complex judgements about whether the occupant is a little anxious at night because they are detected moving around their home during a normal night-time. Such figures can be manually inserted during the configuration of an installation, but they are often not that accurate and can change with time, and with the time of year. Using bed-occupancy and light sensors it is possible for the installation to make a judgement about what is night-time for the user, based on a statistical interpretation of that data. Some judgements are much harder. It has already been commented that making behavioural judgements from simple sensor data is not at all straightforward and clearly this is a complication for adaptive systems. The work completed on lifestyle monitoring has also concluded that the variability in people's behaviour within their home is very large. Nevertheless this is an important area of research which will have profound effects on intelligent home installations once successful approaches have been found. The artificial intelligence community has explored a number of approaches to this problem, and this work is bound to lead to installations that will apply a much more sophisticated interpretation of sensor data and enable them to much more closely resemble the actions of live-in carers in the way they adapt to the individual's needs.

A key area for adaptive responses is in the use of voice prompts. It was mentioned above that habituation is a problem with voice prompting systems, and if changes could be automated it is likely that they would improve the effectiveness of such reminding systems. Voice also contains a high level of emotional salience. For example, human carers would show a level of irritation if their advice was consistently ignored and this has an impact on the user. Automating these kinds of human responses could tap into learnt human verbal interactions and provide them with a response that more closely resembled a live-in carer. Some work on providing video avatars with emotional communication through facial expression has also shown its potential impact on the user who is being communicated with.

Empathic homes

A key advantage of human carers is that they are sensitive to how the user is feeling and can tailor their response accordingly. Providing installations with this kind of sensitivity could improve their effectiveness even further. If the user is showing signs of feeling a little sad or depressed the installation could respond by suggesting it played some music, or perhaps made a cup of tea. Such sensitivity requires not just monitoring user's behaviour but much more closely their body language and their patterns of movement, as well as facial expression. Much of this sensing would require video data processing, and the important and rapid developments of work in this area may well find very useful application in the field of intelligent homes for these kinds of applications.

Conclusions

The use of smart homes to support vulnerable people is still in its infancy but is already showing that it can provide a high level of support. The basic sensors and support equipment technology is quite simple, and the key to its success is in the way the smart home installation is configured using these technologies to suit the needs of the user. Evidence is growing that these technologies are going to provide many thousands of people with improved independence and control of their lives, and should become quite mainstream in the years ahead.

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