

# The Millennium Home: Domestic Technology to Support Independent-living Older People

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**Abstract.** The number of older people in the population is increasing, and the problem of supporting a good quality of life for an ageing population is greatest in developed countries such as the USA, Japan and Britain because of the demographic structures of these countries. In Britain, improvements in quality of life and lower birth rates have resulted in those over 65 years of age representing 16% of the population, with this figure expected to rise to 19% in the first quarter of the 21st century. Many of these older adults, for reasons of personal choice and economics, will continue to live independently with a large number of them living alone. However, the elderly are far more prone to accidents in the home and often lie injured and undiscovered should one happen. It is in the interest of society in general that some way be found to detect early manifestations of problems they may have and provide some kind of a response to resolve the problem or summon external aid as quickly as possible. This also needs to be done in a way that the resident is comfortable using, is useful to them, and is usable. This paper provides details on the work to date of the Millennium Home project, which uses a combination of unobtrusive sensors, linked to a computer to monitor the well being of the elderly resident. Should a situation arise where the residents well-being may be threatened, the system will communicate with them in an attempt to resolve the situation or contact an outside party for assistance.

**Keywords.** Interface design, domestic technology, independent living, seniors.

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## **Introduction**

Most people are aware of the effects of ageing but few fully appreciate the extent to which it changes the way in which older adults live. General biological ageing occurs, resulting in problems with strength, dexterity, gait and mobility. Eyesight and hearing deteriorate leading to difficulties communicating with others. Psychological ageing also occurs leading to diminished cognitive abilities. Its effects include memory deficits and difficulty with tasks where attention is divided or there are unexpected forms of presentation. Any one of these problems can have a severe disabling effect and in most cases, older adults have more than one problem to contend with. The very old (over 85 years of age) can be particularly frail and have little ability to cope with minor health and environmental challenges. This increased frailty exposes them to a greater number and degree of challenges in everyday independent living. They are, not unexpectedly, one of the groups of the population most vulnerable to accidents, particularly in and around the home. Those living alone are particularly at risk with falls presenting the greatest danger. Approximately 75% of domestic accidents for people aged 75 and over were falls (Wright 1994). Furthermore, accidents such as these may lead to a decline in self-confidence and increasing social isolation.

A team of researchers and industrial partners led by Professor Heinz Wolff at Brunel University are currently involved in the Millennium Home (MH) project which aims to provide a solution to the problem. The MH system will be retro-fitted to existing homes as well as incorporated into new homes, and will use existing technology in order to monitor the state of the resident in order to identify potential or immediately threatening conditions. Our team is developing the resident/house interface to facilitate communication between the elderly occupant and in-house computer system. The human computer interface, or more precisely, the resident-house interface, integrates the various technical and social elements of the project and allows the resident to interact with the house/ MH computer. At the core of the project, we are using speech-based interaction, which is critical because of the ubiquitous technology environment, but also, its novelty provides us with problems in that it is a radical departure from existing systems. There are a number of difficulties faced in the development of interfaces for the elderly. These include physical difficulties, in their hearing, their vision, in

terms of their speech/vocalisation, which may be impaired, as well as reduced mobility. They may also face a general degradation in their cognitive abilities. Cognitive impairments include the following factors: a tendency for reduced adaptability to novel situations, divided attention and distraction problems, and possible Alzheimer's disease, including senile and pre-senile dementia (covering memory loss, paranoia). There are often problems of compound impairment, where problems of physical well-being interact with limited cognitive problems.

### **The MH project**

The MH concept was formulated by Professor Heinz Wolff and his team at the Brunel Institute of Biotechnology in Brunel University. It was conceived in response to the increasing numbers of older people in the general population and the associated social and financial difficulties that entails. The concept envisioned a home environment that would be equipped with simple and cheap sensors to monitor the state of the resident. Information from these sensors would be interpreted by an in-house computer that will only communicate with the outside world if there is a situation that cannot be resolved by interacting with the occupant. Any outside communication will be routed to a newly developed local support group, and a volunteer will respond by visiting the tenant.

### **THE MH TECHNICAL INFRASTRUCTURE**

The MH project is intended to provide its users (residents) with an intelligent alarm. This will have a degree of intelligence, and will allow the resident the ability to communicate and interact with it. When appropriate, it will ring out of the house for assistance. A primary aim of the MH project is that it should use existing affordable technology where possible. We are constrained by budgetary considerations, as this is intended to be used as an affordable commercial system at the end of the development process. While the final decision on the specific technologies to be used will not be made until later in the project (work is ongoing at Brunel on sensory technology and configuration as well as interface design), it is likely that some of the following will be used to monitor the state of the tenant:

- ❑ Passive infra-red sensors (PIRs) to detect movement
- ❑ Custom made pressure sensors which will be placed underneath the legs of chairs and beds to detect whether the user is sitting or lying down
- ❑ Burglar alarm style sensors on windows and doors
- ❑ A simple custom-made body count sensor on the main entrance to the property so that the system will know how many people are in the property at any one time.

Work is ongoing on a number of accessory devices, such as special door locks that will normally only work with the users own key but will, in an emergency, respond to a special passkey used by appropriate outside help.

In addition, the house will have to interact with the tenant. This will be performed through a multimodal interface, based around speech, because of the users expected limited computer skills and the context within which the system will be used. This multimodality has led to a number of interesting issues in linking different media (e.g. menu navigation across the different media). The system will communicate to the resident through:

- ❑ Loudspeakers placed in all rooms
- ❑ The television screen (activated though a computer)
- ❑ The telephone, which can ring the resident (activated though a computer)
- ❑ The resident will also communicate with the system through:
  - ❑ Voice recognition
  - ❑ The activation of environmental sensors (e.g. shutting a door)
  - ❑ A yes/ no button for simple communications

In order to enable voice recognition, we have the ability to shut off some noisy domestic equipment from the mains using the X10 protocol.

Dialogues with the resident are rarely a simple matter of yes/no answers, but will often involve extended dialogues. These will depend on the complexity of the required interaction, the location of interactive events, as well as the residents verbal/hearing limitations. Designing speech interfaces provides us with a challenge from three directions: the technological concerns (e.g. recognition accuracy); the psychological concerns (e.g. an ephemeral signal); and interactional concerns (e.g. issues of navigation). If we link these with the problems of the

MH users (the acceptability of technological intrusion into peoples lives; the psychological limitations of its residents, such as limited memory issues or confusion; and interactional problems, such as little previous experience with technology), we can see that designing the system will be more complex than it may initially appear.

## **Previous work**

The notion of an intelligent home is not new. A “house of the future” has been developed at the Massachusetts Institute of Technology which has sensors embedded “into the fabric of the home” (Larson 2000). A research initiative named the *Aware House* (Kidd *et al.* 1999) at the Georgia Institute of Technology is on-going. This is not a not a retro-fit but a house built for \$700,000. It perceives and assists occupants, with sensors in chairs and furniture, video motion detectors, and even a “smart floor” which can identify the occupant by their footprints.

In addition to smart house technology, this has been applied to an extent to the elderly in the Gloucester Smart House,<sup>1</sup> which supports residents with dementia. It monitors the bath temperature, cooker, ambient temperature, and provides night-time toilet guides (via lighting), as well as other assistive technologies such as a picture-phone, and forget-me-not technologies (e.g. to help find keys).

## **PROBLEMS IN THE TECHNOLOGY-LED DESIGN PROCESS**

Prior to the start of the project a prototype MH system was developed. The design, however, was technology-led and the functionality of the system was based on what the small team of developers and engineers involved thought would constitute an adequate system to meet the needs of older people. However, choosing a particular technology and then working backwards by trying to use it to meet user requirements is fraught with problems. There is a general tendency to try and make the users requirements fit the technology, when the focus of a user-centred design should be on ensuring that any technology used is *appropriate* for the particular needs and requirements of the target users (Norman 1986). There has been no exception to this in the Millennium Homes project. From the moment we joined the project we have had to

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<sup>1</sup> <http://www.bath.ac.uk/Centres/BIME/projects/smart/smart.htm>

challenge the existing design and designers with reasons as to the importance of this user led approach. We have therefore taken a standard user-centred approach to system development, rather than a radical approach to accommodate the concerns of the rest of the design team. User centred design (Newman and Lamming 1995; Schneiderman 1992) places the users at the heart of the design process. As older adults represent a very large user group with a diverse range of physical and cognitive abilities it is vital that we begin the development process by focusing on their specific needs and continue to maintain that focus throughout development.

### **Approach to design**

The first consideration of our team was to continue development of a functional specification that would build upon the work completed as part of the initial prototype. Previous work on design for the elderly and disabled has been based on user centred principles (Hypponen 1999) but acknowledges that choosing suitable methods to accommodate these users into the design process is not clear cut. We have chosen methods that are similar to those used in the field of Human Reliability Assessment (Kirwan 1990) because this discipline shares many of the key goals of protecting human life and health with the MH project. The aim of this aspect of the research is to describe the functionality of the MH system in terms of inputs (events or behaviour to be detected) and outputs (e.g. communication with the resident). This began by defining all tasks and activities that constitute independent living and for each of these, assessing the consequences if they are not performed correctly. These consequences may result in situations that arise within the home that have negative consequences for the resident and thereby endanger their well-being (by situation we mean any activity, occurrence or state of affairs in the home that might affect the residents ability to continue living independently). Potential elderly users and their carers were then consulted to decide which of the identified situations should be further analysed. The system behaviour for each of these situations will then be defined in terms of communication protocols between the resident and the MH system. These protocols are discussed in a later section.

## Requirements gathering

As part of the user centred design process it was vital that we had the involvement of independent living older adults and their carers in determining early system requirements. A series of focus groups were conducted to elicit information on the list of situations thought to make up the tasks of daily independent living. The aims were:

- To ensure that the identified tasks of independent living were valid and complete
- To discover which of these the participants would like the MH system to detect
- To categorise each situation in terms of seriousness and the time frame for concern, where participants specified how long they would expect to wait before an outside party was notified of the problem.

The results revealed a series of situations that we have classed as Level 1 and Level 2 inputs. Level 1 inputs indicate that a serious negative outcome has occurred in the home that would require outside assistance within minutes.

1) Incapacity in the resident as a result of:

- Injury
- Falls

2) Intruders in the home

Level 2 inputs indicate events that could lead to serious negative outcomes (detailed in Level 1 inputs) if not addressed properly. An aim of the system is to deal with these inputs wherever possible to prevent Level 1 inputs occurring.

- 1) Temperature regulation of the home environment
- 2) Management of existing medical conditions – ensuring medication is taken
- 3) Management of sudden onset medical conditions – where the resident would require prompt medical assistance
- 4) Home security – appropriate monitoring of all entry and exit points.

This initial data collection has helped to more clearly define the functional requirements of the MH system. Further requirements gathering will take place as part of user testing and evaluation.

## The design process

This will involve multiple iterations and regular user testing and evaluation with each iteration becoming progressively more refined. The first step in this first iteration of the process was an analysis of the situations highlighted in data collection (these will be referred to as alarms or alarm states from this point forward) and is described in the next section. Based on this initial analysis the resident/home interaction for each different alarm was modelled using flow charts. These flow charts attempt to provide a generic guide to the house response for different classes of alarm as well as sufficient fine-grained detail to allow the various stakeholders to provide input concerning aspects such as the timing, number and type of communication with the resident. This is discussed further in the section on protocol design.

### PRELIMINARY ANALYSIS AND IMPLICATIONS FOR HIGH LEVEL DIALOGUE DESIGN

Having determined what situations the MH system should aim to detect, this next stage involved determining what the system should actually do after detecting a given situation. There are many factors that can influence the interaction between the resident and the MH system. What follows are examples of typical questions raised and the answers suggested during this analysis phase. An alarm state indicating the resident had a fall is used. Basic factors that influence how an interaction is conducted include:

- *Time of Day*: Should not have that much bearing on this interaction. We can assume that the resident is awake. Even if resident fell out of bed while sleeping we will assume that the fall would wake them.
- *Resident Activity*: What is the resident doing? There should not be any activity because the MH has already detected a fall. We assume that if there is activity, it will be minimal and will not be detected by MH.
- *Resident Location*: The location of the resident dictates which devices (microphones, speakers, visual displays etc.) will become active to facilitate the interaction.
- *Level of Urgency*: This relates to the previous incidence of alarm states within the home and how they affect the urgency with which the system considers the current

alarm (default condition will be nil, or predetermined by carer). The factors above may also influence this (weighting and factoring to be determined).

These will then dictate the constraints on the communication with the resident so again, using falls as an example, we must consider:

- *Which mode of communication will be employed by MH system?* Speech will be used for first communication with resident. It is a quick method of alerting the resident to the fact that the system is aware of the alarm state and may also be the only possible mode of communication, given that they may not be able to move. If the resident does not provide feedback (i.e. a response that the system can understand) then the system should continue to use speech throughout the interaction. If resident does provide feedback and it is not understood speech will continue to be the dominant mode.
- *Which mode of communication to be employed by the resident as feedback?* Speech or tactile (such as the press of a button). Environmental action (the detection of a door or window being opened or closed) will not count as feedback. Only manual feedback will return system to safe state – manual communication indicates that the resident is conscious, has motor control (maybe not fully mobile but feels that they can deal with it themselves without the aid of the system) and is aware of what the implications of returning system to safe state are (i.e. no further help from system unless they request it)
- *How long should the system wait between each act of communication before attempting a subsequent communication?* It is suggested that a period of 3 to 5 minutes plus system processing time. This is an extremely urgent alarm state and it is reasonable to assume that if the resident is fine they will be able to provide feedback within 3 – 5 minutes, even if they have to locate a device for tactile input.
- *How many times should the system communicate with the resident to obtain feedback?* There should be some method, such as a timeout feature, whereby the system will automatically request outside assistance if the alarm is not satisfactorily resolved within a certain period of time (which would not be very long in this case). The number

of communications would then be dictated by the interaction timeout length and the timing gap between system communications specified in the previous question.

- *Can incoming data from the MH or other alarm states terminate/change current communication?* Once a fall has been detected and communication with the resident has begun, the interaction must go through all relevant stages before returning to safe state unless, another alarm state has been detected of equal or greater importance. The alarm state can be terminated by appropriate manual feedback from the resident or a call or visit from a carer
- *When will a call be initiated by the MH system to the call centre?* In the case of a fall, when system terminates communication with the resident (see above) or when the resident provides feedback that they are not ok and need assistance
- *When a call has been initiated by the system – does the system communicate further with the resident?* Yes. The system should provide reassurance and inform the resident that a carer has been notified.
- *How many times should reassuring messages be communicated by the system to the resident after a call has been made for outside assistance?* If unconscious the resident will not hear the message. If conscious, however, they may find repeated system communication exacerbates what is already an extremely stressful situation for them. The presence and timing of these messages will need to be dictated by the individual resident and their carers.
- *How will the system terminate communication with the resident?* On arrival of the carer or detection of a phone call being made by a carer (if this is possible) and the resident answering the call. The system should inform the resident about who is calling or letting themselves into their home (this will be detected by the lock system being developed for the MH). If the resident provides tactile feedback that they are okay, the system should acknowledge this and inform the resident that it will return to safe state.

## PROTOCOL DESIGN

After the initial analysis was conducted it was felt that the next step should be to attempt some form of graphical representation of the sequence of events and flow of activities that made up each alarm state. Many of the questions raised during the analysis phase remained without conclusive answers. The various stakeholders would need to be consulted at this stage and to do this a representation of the proposed design was needed that would not require any prior technical knowledge on their behalf. It should also be capable of communicating some of the more fine-grained aspects of this phase of the design process. It was not just the stakeholders that were taken into consideration when choosing a suitable representation. The design team contained individuals that were not from a technical background, so this choice had to accommodate their lack of practical design experience.

Flow charts were chosen as the method of representation because of their relative simplicity and the ease with which they can be learned. While they may not necessarily continue to be utilised in later design iterations, they proved to be an excellent common language for all concerned at this early stage of the process. Figure 1 shows a high level flow chart of the two classes of alarms identified in requirements gathering. At this high level of detail the different classes are almost identical. Both alarm classes attempt to get feedback from the resident in two stages. Stage 1 involves a number of cycles of communication (the difference between the two here is the acceptance of environmental feedback from the resident in certain Level 2 alarms). If this fails to gain appropriate feedback there is a second stage that is a final attempt at gaining feedback before the system notifies an outside party. The most significant differences between the two classes, however, concerns the levels of urgency and the time frame within which activities occur. These will most likely be different for each alarm state. Figure 2 shows a table detailing some the communication, feedback and timing issues that need to be addressed for the different alarm scenarios.

## **Current and future progress**

Detailed flow charts of each different alarm situation are currently being developed. The generic interaction structure shown in Figure 1 will be used to help develop the various context-targeted interactions with resident. These will be shown to all stakeholders for assessment and the necessary changes will be made in a second series of flow charts. Another issue currently being considered is how urgency management should be incorporated into the design. This is an important aspect and will need to be dealt with carefully. Spiralling danger levels in the home will need to lead to modified interaction with the resident. There should be increased urgency in dialogues in these cases and possibly fewer warnings before an outside party is contacted.

Much work still needs to be done and there are still some basic design issues that have yet to be resolved. The prototype system being developed will have difficulties if there is more than one individual in the home. A suitable way of sensitively assessing house occupancy will be required. A body count sensor on entry points has been developed but can have problems if two people enter side by side. It only sees one person instead of two. An alternative way of determining if there is more than one individual in the home is required and will most likely be another form of verbal interaction between the MH system and the occupant. Interaction scenarios for all contingencies (alarm-related scenarios and non-alarm related) will need to be developed and an iterative evaluation process is planned. A heuristic evaluation of the first flow charts will be conducted to ensure that the basic design adheres to the tenets of interface design. The second phase of evaluation will most likely involve the use of the developed flow charts as verbal prototypes that can be evaluated by stepping through each interaction scenario to check that all eventualities have been accounted for. The next stage will involve implementing the design in the form of software prototypes. Development will be an iterative process with subsequent prototypes becoming more refined. Various pilot homes, where the MH system can be tested in a real life environment, have been established and considerable user testing is expected to take place here.



ALARM	Mode of first communication	Max number of subsequent communications	Is feedback from resident required?	Type of feedback required (Stage 1)	Input device used for feedback (Stage 1)	Type of feedback required (Stage 2)	Input device used for feedback (Stage 2)	Max time from alarm start to alarm end or callout
<b>Fall</b>	Speech	4	Yes	Direct (Speech)	Microphone	Direct (Tactile)	Telephone	30 minutes
<b>Inactivity</b>	Speech, Visual display, Telephone	4	Yes	Direct (Speech)	*Input Box	Direct (Tactile)	Telephone	31-60 minutes
<b>Medication reminder</b>	Speech, Visual display, Telephone	4	Yes	Direct (Speech)	*Input Box	Direct (Tactile)	Telephone	31-60 minutes
<b>Temperature too low</b>	Speech, Visual display, Telephone	3+	Yes	Environmental	Thermostat	Direct (Tactile)	Telephone	60+ minutes
<b>Window open</b>	Speech, Visual display, Telephone	3+	Yes	Environmental	Window sensor	Direct (Tactile)	Telephone	60+ minutes
<b>Door open</b>	Speech, Visual display, Telephone	3+	Yes	Environmental	Door sensor	Direct (Tactile)	Telephone	60+ minutes
<b>Door shut But not locked</b>	Speech, Visual display, Telephone	3+	Yes	Environmental	Door lock sensor	Direct (Tactile)	Telephone	60+ minutes
<b>Intruder</b>	Visual display & Telephone	N/A	Yes	N/A	N/A	N/A	N/A	N/A

Figure 2. Alarm look-up table

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