CHAPTER FOUR

Monitoring Systems

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1 INTRODUCTION

The following chapter reviews Monitoring systems from a number of perspectives within the home. To begin the review, the case for home and mobile monitoring is developed by investigating societal needs. Areas where health and wellbeing can be enhanced by the deployment of home systems are considered. Both technical and non-technical barriers to adoption are considered. Factors such as the cost of systems, perception issues and environmental factors are discussed.

The chapter then goes on to review the common 'markers' or parameters that are used to assess both physiological and emotional wellbeing. It also looks at the current state of the art commercial devices that can be deployed into home environments and compares current product offerings.

Technical issues that are preventing more widespread usage of such systems are then considered and include sensor power consumption, network reliability and broadband proliferation. Finally data analysis and fusion methods commonly employed are examined with examples of user interfaces to demonstrate how user-centred these devices must be.

Note: Follow the links within the text for more information on particular subjects from the CAPSIL Wiki

Links to CAPSIL Wiki

Further information on issues discussed in this chapter can be found on the CAPSIL Wiki at this link

Online versions of this chapter and other chapters from the CAPSIL Roadmap can be found on the CAPSIL Wiki at this link

2 RECOMMENDATIONS & ACTIONS

The recommendations in this chapter have been derived from the list of challenges described in Section 11. Recommended actions include the initiation of studies to gather evidence, empirical studies of the design requirements, development of technology and initiatives to remove existing legal, political and economic barriers.

Empirical Evidence

One or more empirical studies are needed to examine the effectiveness of remote monitoring and its consequences for provision of care and independent living. These studies should be performed on a scale, with sufficient statistical relevance to permit conclusions regarding the monitoring technology and its impact on the elder's care and independence. These pilots should demonstrate reliability, security, privacy, interoperability and ease of use, as well as business value. This requires significant investments and diversity of designs in order to come up with generalisable conclusions. These studies should not be proprietary or follow a specific commercial interest.

Interoperability across various health records should be demonstrated. It is preferable to carry out pilots based around chronic conditions programs, such as congestive heart failure and diabetes, as well as ageing-in-place programs. These programs will show a higher return on investments as opposed to targeting the general 'well' population.

Scalability and Platform

The success of technology-based approaches is predicated on its ability to scale the monitoring and intervention systems to a large proportion of the population. Increasing the number of monitored individuals from several hundred – in the largest ongoing trials – to 10.000 and 100.000 requires drastically different designs than those implemented in current studies.

This will be a significant effort that will probably require close collaborations among academics, industrial organisations and care giving partners. The scalability requirement in conjunction with the diversity of devices, environments and people dictates that the ultimate system must be a flexible platform that would support devices and algorithms, which are yet to be invented. Such platforms must be relatively open so as to minimise the barriers to entry for small and large developers and inventors.

Next Generation Sensors

With advances in areas such as nanotechnology and micro-mechanical devices, combined with the emerging demand for monitoring wider ranges of phenomena, there is a need to develop new, more effective sensors.

In particular, there will be a need for novel solutions to sensors specialised in location monitoring, medication monitoring, interacting with various objects and physical exercising, etc. This expansion will require novel sensor designs for multiple modalities including acoustics, imaging and vibration. Among the consequences of 'The Internet of Things' is a strong trend towards devices becoming smaller and more pervasive. The research in to wearable devices needs to be supported, as does the work in to sensors requiring lower power consumption, higher reliability and higher security. Research needs to continue in to alternative power sources and power scavenging methods

Autonomic Networks

More work is needed on the self-organising properties of sensor networks, including end-to-end pilot studies. The *Reliability Dilemma* is also of critical importance, ensuring the data is secure and reliable. A key feature of autonomic networks is its ability to adapt to new and changing environments. Integration within hierarchical network structures will require seamless operation among a variety of networks including combinations of WIFI, WiMax, 4G, etc.

More information on specific recommended actions for sensor networks can be found in the WBSN CAPSIL

Algorithms for Statistical Inference

Advances in sensor technology must be matched by algorithms capable of maximising the utility of data with respect to a task, e.g. early diagnosis, maintenance, intervention etc. Among the important objectives will be the detection, classification, and assessment of activities of daily living extended to instrumental and other key activities.

The unobtrusive nature of monitoring technology will require new techniques for inference. The challenges to inference techniques will also include the detection and classification of novel and unexpected events. This is a significant problem for statistical pattern recognition and machine learning because it requires generalisation well beyond the available training sets. For example, the detection of falls will require inference techniques with minimal training sets.

Novel approaches such as those investigated by dircaproject are among the possible directions of future research. The detection of unexpected events includes the detection of sensor malfunction and contamination of the raw data. Finally, much like the sensor systems, these inference techniques will need to adapt to new and changing conditions.

Standardisation

Commercial systems must be compatible with each other to allow for custom installations of home monitoring technologies and ensure their compatibility within the wider healthcare system. A vital part of this is standardisation of personal/ electronic health records to allow meaningful access for diverse solutions.

Usability and Workflow Integration

Advances in monitoring technology must be complemented by equally sophisticated designs of the interactions between humans and the monitoring systems at all different levels.

Policy and Legal Framework

In parallel with the pilots, a group should be working on the detail involved in the data ownership, data flow, security, accountability and reimbursement models. A lot of work has been done by organisations such as the American Telemedicine Association and the Health Policy Institute of Japan (HPIJ), as well as European research projects; lots of work can be leveraged. The legal side also needs to support the pilots proposed to enable progress in the area.

Clinical and insurers involvement may be limited if the threat of litigation is not alleviated. Trans-jurisdictional healthcare licensure to mitigate the risks of litigation to legal frameworks needs to be established.

Privacy Legislation

Privacy legislation needs to be drafted to deal specifically with telehealthcare issues. Currently in Europe telehealthcare comes under various acts and directives, none of which were designed specifically for telehealthcare.

Reimbursements

Healthcare insurers need to be incentivised to get involved in pilot activities around telehealthcare. Specific research programs need to be put in place to do the basic research on how the financial supply chain would work in the event of a widespread telehealth adoption. Much advocacy and consultation is needed between the end users, the clinical people, the insurers and the technology community. Large-scale surveys and market studies are needed among these groups. The ‘how to’ questions need to be resolved, starting with chronic disease management programs.

3 MONITORING SYSTEMS DESIGN CHALLENGES & CONSIDERATIONS

A key component of the future elder care systems is a comprehensive data gathering capability. This section provides an overview on the state of the art in the field of monitoring as applied to sensing in independent living applications, both in the commercial and research context.

Monitoring Systems (MS) is understood in this context to mean embedded sensors and sensor networks that integrate with mobile devices such as Smart Phones, and provide data to a centralised system for analysis and, if required, action. Key design considerations of MS will be outlined and gaps identified for further research.

Many of the considerations connected to sensing & sensor networks are also relevant to the field of Wireless Body Sensor Networks (Chapter 5), particularly those to do with mobile sensing and will cross reference to this chapter.

The development and design of MS that integrate seamlessly with care giving and support independent living present a number of challenges. These challenges arise from the heterogeneity of the population and complexity of care and range from broad issues related to specific illnesses (e.g. dementia), cost & reimbursement, sensor data fusion, interoperability and standardisation to low level issues related to embedded or mobile sensor networks such as power, scalability and reliability.

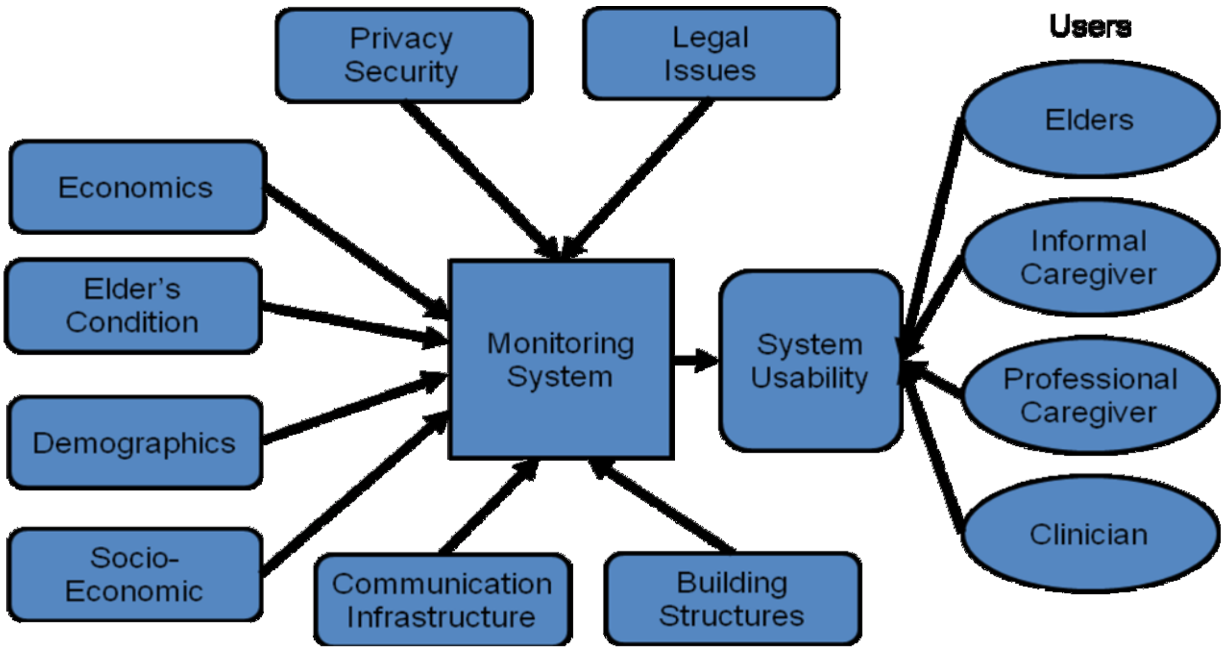

Figure 1. Components of Home and Mobile Monitoring Systems

The ability of an elder or chronically ill person to live independently depends on a multitude of functions including, but not limited to physical, medical, emotional and social components. A graphical summary of these issues is shown in Figure 1.

The categories of information important to assess by any ambient, monitoring system in order to support elders living independently, safely and with high quality of life include:

Behavioural Measurements

Physiological Measurements

Assessment of cognitive Function

Detection of adverse Events

3.1 Behavioural Monitoring

Critical assessments, which need to be carried out on a continuous basis for ADLs such as:

- Nutrition
- Dressing
- Ambulation
- Toileting
- Bathing
- Transfers (bed <-> toilet)
- Continence
- Grooming
- Communication

In addition to these higher-level functions, instrumental activities of daily living (IADL) [1] include the following categories:

- Writing
- Reading
- Cooking
- Cleaning
- Shopping
- Doing Laundry
- Climbing Stairs
- Using Telephone
- Managing Medications
- Managing Money
- Outside work /employment
- Travel - public transport / driving

A number of the IADL of an elder living independently can generally be aided or performed by formal or informal caregivers, but the elders are losing aspects of independence as caregivers take up this role.

In addition to the ADL and IADL, it is important for elders to retain and possibly enhance their functionality and independence. These supporting activities of daily living (SADL) necessary to maintain QOL include, include but are not limited to:

- Sleeping
- Physical Exercising
- Cognitive Exercising
- Socialising

In an ideal situation, both ADL and IADLs would be monitored n real time in order to determine the type and the intensity of care need for the particular elder. The need for assessments of ADL, IADL as well and EADL present the most difficult challenges to the monitoring systems: continuity and un-obtrusiveness.

Ultimately continuity is required because of the unpredictable sequencing of actions and activities that need to be detected recognised and assessed. Unobtrusiveness is necessary because of the fact that people in general and elders in particular have difficulties with adherence to periodic specific procedures, e.g. wearing a monitoring device whose effect is not immediately sensed, e.g. medication taking, or exercising.

3.2 Physiological Measurements

Control and treatment of various chronic illnesses can be aided through home monitoring systems that measure physiological indicators of the illness and provide feedback to the user along with related healthcare professionals.

Examples of physiological measurements used in the treatment of different diseases can be found in Chapter 1.

3.3 Cognitive Function

Cognitive function and its maintenance have been shown to be among the foremost concerns of elders, as well as a key determinant of their independence. Some decline in cognitive function is associated with ageing, but there appears to be an increasing amount of evidence that cognitive and physical exercise slow down the decline. This is likely to be true even in the case of morbidities such as Alzheimer's or Parkinson's Diseases. Frequent or continuous assessment of cognitive function is therefore a component of the monitoring system.

Cognitive functions may be assessed through a variety of approaches ranging from formal testing to the unobtrusive inferences made from behavioural assessment and monitoring. These approaches depend on the specific aspects of cognition and generally include memory, executive function, attention, speed of processing, and aspects of sensory-motor functions.

There is evidence that behaviours such as speed of walking or finger tapping can be used as predictors of future cognitive performance [2]. In addition, monitoring elders' usage of language and extracting aspects of language such as verbal perplexity and grammatical complexity are also predictors of cognitive function [3].

In outlining requirements for monitoring systems, it suffices that monitoring of a wide range of behaviours appears to be useful for a variety of inferences ranging from early detection of subtle cognitive decline to memory lapses and adverse events due to suboptimal attention allocation.

3.4 Adverse Events

In all of the above, detection of rare, unexpected and incongruent adverse events is critical in order to support independent living. The two aspects of monitoring of adverse events are:

- **Detection of known class of events**. A prototypical example is the detection of falls, burns or a subset of social faux pas. A more general class of a priori known adverse events are those that occur on slower time scales and are less well defined, such as periods of depression or delirium.
- **Detection of unexpected, unpredictable events**- events specific to the monitored individual & difficult to define a priori. In some cases these events may include the entrance of an unknown person.

The key challenge for both types of adverse events is that it is almost impossible to develop databases with examples that could be used to define the event classes and to train the inference and pattern recognition systems. This requires the monitoring system to sense as wide a range of observable signals as possible

4 MONITORING TECHNIQUES

This section focuses on techniques and devices that provide raw data necessary to assess and support independent living for healthy elders as well as for those with chronic diseases.

4.1 Behavioural Measurements

This section provides a brief overview of devices aimed specifically at the residential care and nursing home environments. The physiological measurements discussed in the previous section are still valid here however the emphasis in this environment tends to be more on proactive care, preventing behaviours and activities from becoming medical conditions, and generally supporting the person in their Activities of Daily Living (ADL). For example, preventing pressure ulcers (bed sores) is crucial in this setting as these can be potentially fatal (second highest cause of iatrogenic mortality in the US, behind adverse drug events). In this case sensor devices can be used (motion sensors, enuresis sensors) to give early warning.

As noted above, mobility is a key determinant of the ability to live independently. In addition, there is recent evidence that aspects of sensory motor control and, in particular, mobility can be indicators – markers – of an individual's cognitive state.

In combination with the utility of monitoring mobility for the purpose of care giving, researchers began to study ways to use unobtrusive measurements of movements and other activities within the elders' homes for long periods of time [4,5].

A typical example of this approach is a study based on small sample of 8 elderly people monitored for 2-20 months, using a single pyro-electric motion detector in each room [6]. In addition to the reduction in the gait velocity, a decline in cognitive function can be reflected in increased variability, at least for individuals with Mild Cognitive Impairment, as compared to healthy elders [7]. Specific devices include:

Motion Detectors

These devices are simple and usually operated within an area such as a room or corridor to give an alert of activity or inactivity. This may be important for example if a person has not moved from a bedroom to toilet, then bed-wetting may be an issue. Also these devices can be used to detect when a person (for example and Alzheimer's patient) leaves a particular space or 'wanders'. These devices usually use infrared technology and are placed between the wall and ceiling.

Location Sensors

One of the fundamental types of raw data that underlies behaviour-based inferences is the ability to assess the location of the monitored individuals. Instantaneous location assessment and individual identification is a particularly critical capability for the majority of people that do not live alone, but need to be monitored. The currently available systems are either very unreliable or they are too expensive.

Bed Sensors

These devices sense the presence and movement in bed by measuring either pressure by a pressure mat or by load cells installed in the frame of the bed. Depending on their sensitivity and sampling frequency, these devices can be used to give an indication of the length of time a person spends, any restlessness and repetitive movements in bed and also in getting up from bed (transferring). Many falls occur when a person is transferring from bed to a chair or walking aid. These sensors can also be used in the prevention of pressure ulcers (bed sores) where by the sensor gives an alert that the person needs to be turned or moved in the bed. An example of one such sensor device is Alimed™ Hard Wired Bed Sensor Alarm.

Figure 2. The Alimed™ Bed Sensor Source:http://www.alimed.com/Alimed/product/AliMedreg-Bed-Sensor-Alarms,15137,280.htm

Pressure Sensors

These may be installed in key areas of the home to detect presence and transition from area to area.

Enuresis Sensor

This sensor device fits between the top bed sheet and the mattress. It detects moisture as an indication of bed-wetting and sends an alarm to the caregiver that the person needs attention. Pride and dignity is preserved by not having to check every two hours or so (which is the alternative).

Microphones

These devices sense acoustic signals that can be used for a wide variety of assessments. Using microphone arrays it is possible to infer the location of acoustic sources. Most of the issues associated with microphones concern signal processing, separation of signals from background noise and making reliable inferences.

Power-on Sensors

Measure whether or not a device or a home appliance is turned on or off. This is useful in order to monitor activities such as toasters, microwave and heaters.

Telephone Sensors

Sensing the telephone usage is an important component of many systems ranging from social monitoring to context-based interactive systems such as medication reminding.

Image Sensors

A very ubiquitous class of sensors operating in the visible or infrared regions of the electromagnetic spectrum, capable of monitoring a variety of actives and behaviours. The purpose of these sensors is to acquire images, perform local analysis, categorisation and communicate *only* the categorisation results and not the raw images. E.g. image-based systems are currently the most reliable devices for the assessment of adverse events such as falls.

The main concerns associated with the image-based sensors are privacy, occlusion and environmental dependency. Even if these images are never stored or communicated outside of the device, many individuals still have privacy concerns. Sensitivity to environmental aspects is a result of the need for illumination of the monitored area and concomitant artefacts such as shadows.

Medication Monitoring Sensors

A specialised set of devices that are either built into specially designed medication dispensers or attach to existing dispensers or medication containers. Sensors monitor medication-taking behaviours such as removing a dose from the container.

Although this class of sensors is a key component of care, their current design is far from the ideal. The shortcomings range from the inability of the current sensors to actually sense the taking of the medication dose rather than just removing it form the container to the heterogeneity of individuals' storage of medications (bottles, bags, etc.

There are many other standalone sensor devices that can be deployed to aid in assisting a person with their ADLs including excessive temperature monitors, medication trackers, carbon monoxide alerts and flood detectors. These devices can be applicable to either the home or care facility as the need dictates.

Although many of these devices are currently available there are serious shortcomings including installation, maintenance, power requirements, etc. Perhaps the most important drawback of the currently available systems is the lack of interoperability and capability to integrate into a comprehensive healthcare network.

4.2 Physiological Measurements

The most common physiological measurement devices available are devices that measure fundamental parameters such as blood pressure, ECG, glucose and weight. These are the devices that also have seen a 'service industry' emerge around them, with the idea being that home monitoring devices are not of huge value unless something useful is being done with the data. 'Useful' means that a clinician is monitoring the data or it is being acted upon in some way so as to bring about a general health benefit. This service industry is concerned with closing the so-called home-health triad.

Figure 3. The home healthcare triad showing the feedback loop from home to monitor, to clinical and back to patient again. Source J.Dalton. http://www.daltec.ie

This home healthcare triad is the ideal scenario and will in reality take quite some time for the entire infrastructure to come in to operation (3-7 years) for the basic physiological measurements such as ECG, blood pressure, glucose etc. Various vendors though are offering so-called 'full services' from devices to monitoring to clinical input. However at the moment these 'networks' tend to be standalone and proprietary. Some examples of physiological measurement devices currently available for the home and telehealth user are:

Electrocardiogram (ECG)

Electrocardiogram deploys one, three or twelve leads to sense electrical activity of the heart, one of the fundamental indicators of health of the cardiac system. The raw EEG can be used monitor heart rate and heart rate variability. Heart rate and heart rate variability are among the most useful metrics for health monitoring.

There are several designs that implement EEG data acquisition and communication. They range from the traditional wired holster types to ones implemented in the form of band-aids. These devices may store the data locally until they are downloaded to a more permanent storage or use wireless networks. However the typical wireless device only communicates a short distance with a PDA type aggregator being used to collect data from the on-body sensors.

It is also worth noting that ambulatory monitoring is plagued with a variety of contaminating effects due to environmental diversity and changes in the ECG signal due to changes in the heart position and orientation.

Blood Pressure

There are a number of commercially available devices using cuff mechanisms (see later section). Research challenges here include making devices that don't use pressure cuffs, for example using pulse wave velocity techniques, Doppler effects or impedance-based measurements. The main concerns associated with these less obtrusive techniques include calibration and stability.

Glucose Monitoring

Blood glucose level is a key component of care and maintenance of patients with diabetes. Since this monitoring needs to be performed frequently, there are many commercial devices available (See CAPSIL Wiki). Most of these portable devices require patients to pin-prick their fingers to obtain blood samples. Consequently a research challenge here is the commercialisation of a non-invasive device i.e. no pin-prick needed.

Pulse Oximetry

The level of oxygen in the blood (or oxygen saturation) is another important health indicator. Pulse oximeters use red and infra-red light sources to measure the level of blood oxygenation of the pulsing arterial blood. Typically this device is clipped over the fingertip and uses two different infrared frequencies to discern oxygen saturation from the flow. There are several commercially available but they all require specific actions on the part of the monitored individual.

Peak Expiratory Flow

The peak flow meter is used to monitor a person's breathing effectiveness by estimating the airflow through the bronchi. These measurements can be used to infer the state of bronchial obstruction in acute patients or with individuals with chronic obstructive pulmonary diseases (COPD), bronchitis and other diseases of the pulmonary system.

Weight

A very simple but important measurement is body weight. It is well known that being overweight contributes to health issues such as heart problems and diabetes (the two most common diseases in the world and responsible for the highest incidents of hospitalisation).

Temperature

Temperature monitoring is another fundamental and important measurement. When taken in to account with other markers (blood pressure, ECG, weight etc), it can help give an overall picture of what is happening the person being monitored.

Sleep Sensors

Current physiological assessment of sleep is based on a suite of sensors attached to the monitored individual. These include ECG to EEG and plethysmograph, oximetry. Although well-established approaches, their obtrusiveness interfere with their goals.

Recent advances in unobtrusive mechanical sensors, such as bed load cells are emerging as potential alternatives alleviating the obtrusive aspects of the current clinical approaches.

4.3 Cognitive Function Monitoring

Most of the current methods of assessment of cognitive function are administered infrequently (if at all) in clinics and are difficult to implement in any ambient way. There is a clear need to implement this type of assessment in an unobtrusive manner available frequently at home. Despite their obvious potential, computerised or automated tests have so far shown limited effectiveness.

Clinical Neuropsychological Assessment

Neuropsychological testing is a methodology that has been developed to assess the perceptual, sensory-motor and cognitive functionality of individual patients. Traditionally, these tests are performed in clinics whereby a clinician asks the patient to perform a series of tasks, most frequently using pencil and paper.

A battery of neuropsychological tests typically includes assessment of various functions including memory, verbal fluency, and executive function – a list of many of these tests can be found at [8]. The test is performed by a clinical neuropsychologist and usually takes an hour or longer.

There are several shortcomings of these approaches. In particular, these tests are expensive to administer because they performed in a clinic and require the time of a clinician. As a result, these tests are administered only very infrequently.

Psychological states and conditions such as depression and anxieties have typically been evaluated using questionnaire type of approaches that try to gauge the level of disturbance the person is feeling. A good example is the World Health Organisations Major Depression Inventory (MDI) [9] and the Beck Depression Inventory [10].

Neuropsychological Testing

During the last several decades, a number of the neuropsychological tests have been implemented to run on computers. Unfortunately, with very few exceptions, these implementations require the presence of clinicians and thereby diminishing the potential of a computer-based testing. Many of the implementations are using exact copy of the paper and pencil test and thus suffer from limited flexibility, and yet these are still conducted in a clinical setting. Newer research approaches use adaptive cognitive computer games to monitor analogues to the neuropsychological tests, such as working memory, divided attention, planning, motor speed, and verbal fluency [11].

Examples of intervention trials for those with cognitve impairments include: OASIS Project & Long Lasting Memories Project (Trans-EU), Cogknow Project (Netherlands, Uk, Sweden), ACTIVE (US), Assisted Cognition Project: University of Washington (US), IMPACT(US), ORCATECH ISAAC (US), ORCATECH Cognitive Health Coaching (US) Diakonisches (Germany) , HERMES (EU). For further details see Appendix A or follow the links above.

4.4 Detection of Adverse Events

Fall Sensors

Evidence shows that many falls have been preceded by near miss events. Therefore the detection of near falls has the potential to trigger interventions that may prevent falls. A number of approaches have been used to detect movements that are frequently associated with falls.

Fall sensor devices utilise accelerometers and gyroscopes to detect sudden motion in unexpected directions. They are capable of detecting the difference between a fall and a 'stumble' and work very well in practise. A number of these contain wireless communication mechanisms to alert the caregiver when a fall has been detected. These devices are small and usually worn on a belt clip or as a pendant.

Figure 4 The Tunstall Fall Detector with manual panic button. Source:http://www.tunstall.co.uk/products.aspx?PageID=152

Examples of Fall Detection trials are: Laboratory for Real-Time & Embedded Computing: Fall detection project (US), MARC: Gait Monitoring device (US) Android application: iFall (US), ishoe, myHalo, CAALYX Complete Ambient Assisting Living EXperiment

Despite recent research and development efforts and the diversity of approaches, detecting falls is a very difficult problem. Elders and individuals with neurological diseases are likely to fall in a manner that is indistinguishable from other safe movements. Thus any single modality is likely to be either insensitive or generate too many false alarms. It appears that a fusion of multiple sensor types have the highest potential to optimise performance.

CONFIDENCE is an EU project with a focus on integrating innovative technologies to form a care system for the detection of abnormal events (such as falls) or unexpected behaviours.

5 DEVICES CURRENTLY AVAILABLE

In this section a cross-section of devices available to monitor both physiological and behavioural markers both in the home setting and also the residential/care setting are reviewed. There are many commercial products available therefore only a representative sample is presented.

5.1 Home & Care Setting

Viterion™ [12] – a Bayer Healthcare Company

Viterion offers a range of products for monitoring blood pressure, pulse oxygen, weight, peak flow (spirometer), asthma, blood glucose and temperature. They also have a manual entry system for treatments such as pain management.

Viterion offer a 'full service' from devices to monitoring, to full clinical intervention via their 'Telehealth Network'. Viterion manage the network and ensures its security, reliability and manages access for doctor /nurse/caregiver.

HealthHero™ Network [13]

Another 'full service' that monitors physiological data from blood pressure devices, blood glucose, blood oxygen, weight and peak flow. Many different commercial devices can be connected to the HealthHero 'Buddy' system including Abbott, Roche, A&D Medical and Microlife.

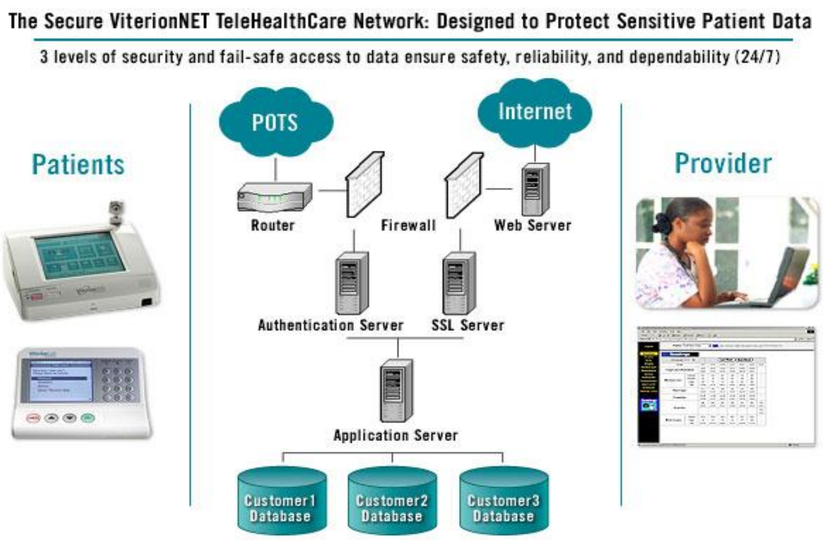

Figure 5. The Viterion™ TeleHealthCare Network showing how security and access control is maintained. Source: http:www.viterion.com

Figure 6. The HealthHero™ System showing the HealthHero 'Buddy' device connected to BP, Glucose, Peak Flow, Weight & Pulse Oxygen devices. Source http://www.healthhero.com

CardGuard™ [14]

A Swiss based company providing telehealthcare monitoring solutions to end users. They provide devices to monitor ECG, blood pressure, peak flow, glucose and weight.

They provide a 'full service' also in that they host a secure network that they administer and ensure its reliability and security. Physicians or other caregivers can be granted access to the patients system and two way communications can happen. They also offer interactive TV and video conference options.

Figure 7. CardGuard™ devices for ECG measurement. Source www.cardguard.com

Philips™ [15]

Philips offers a range of telehealth devices for the home setting also including blood pressure monitor, ECG, glucose monitor, weight scales and pulse oxygen. The devices are wireless using Bluetooth communication and relay data back to a central 'Telestation'- the central server for the healthcare suite, and can be accessed by the clinician and other caregivers. Manual entry of data is also possible (for example in pain management or medication compliance scenarios)

Figure 8. The home healthcare 'Motiva' product offering from Philips showing the various devices plus the 'Telestation'.Source:http://www.healthcare.philips.com/main/products/telehealth/Products/telehealth_solutions.wpd

Intel® Health Guide [16]

The Intel Health Guide product is a newly available suite that contains two parts. Firstly there is a desk top device that can be used with approved devices to take vital measurements (it comes with a full list of approved and interoperable devices, including blood pressure, ECG, peak flow etc) There is also the capability to have video calls (Teleconsultations) with the clinician and to manually enter data (medication compliance, pain management etc). The second part is a sophisticated clinician management application that allows the clinician to easily see which of his/her patients' needs priority of care based on home based test results. This application allows the clinician to communicate with the patient, develop care plans, assign extra caregivers, printout reports and include motivational input over secure and reliable communications paths.

Figure 9. The Intel Health Guide Product PHS6000 showing an interactive session with a clinician in progress. Source:http://www.intel.com/healthcare/ps/healthguide/index.htm

GE QuietCare® [17]

Offering 'proactive healthcare' monitoring concerned with learning 'normal' patterns of daily activity and then determining any deviations from this 'normal'. When a deviation is detected, an alarm is raised and some action taken such as contacting a caregiver. The concept is based on early detection of events and behaviours and proactive correction, thus stopping them from becoming acute medical conditions. For example if a person normally visits the bathroom once per night and suddenly this increases to nine or ten times, it may indicate a serious bladder condition that if acted on early, may prevent a much more serious outcome. The GE QuietCare® system uses multiple motion detectors connected to a central 'learning server'. This server also acts as the gateway to the outside world.

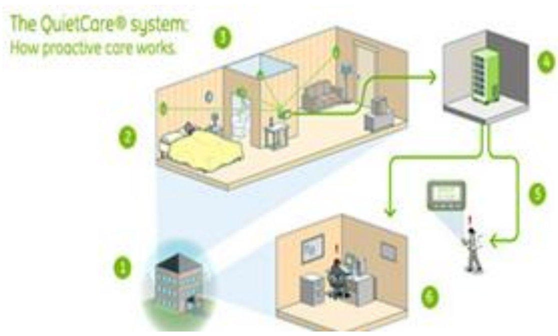

Figure 10. The GE QuietCare® system is based i.e. multiple motion sensors connected to a 'learning' server. Source GE QuietCare [17].

6 PILOT STUDIES AND SMART HOMES

In response to need, there has been an increase in the number of studies and projects exploring technological solutions to the development of supported independent living. However, a relatively expensive, longitudinal trial is required in order to provide the incentive for private or governmental organisations to invest in trials to test these solutions at a larger scale.

Despite this problem, there are several studies focused on gathering evidence related to the ability of technical solutions to support independent living.

Currently, one the largest ongoing longitudinal trials at the Oregon Center for Ageing & Technology (ORCATECH) in Oregon Health & Science University comprises monitoring of over 230 community dwelling individuals [18].

This trial, funded by the National Institutes for Health, is focused on early detection of cognitive decline. Inexpensive passive and unobtrusive monitoring is used including motion detectors, contact switches medication tracking devices and computer for monitoring computer interactions. The setup of a typical house is shown in Figure 11

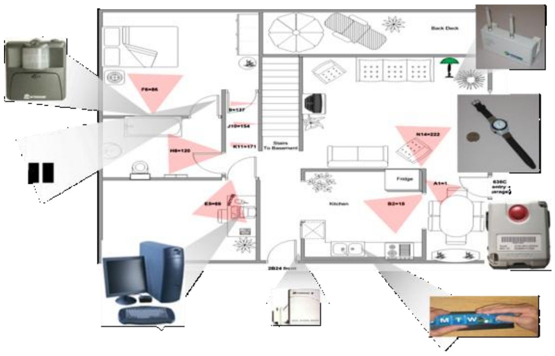

Fig. 11: Floor plan of OHSU home sensor test bed. Source: ORCATECH

Another smaller on-going study involves monitoring of 17 apartments in an elder care facility in Columbia, Missouri [19] for more than two years. The sensor network deployed included motions, video and bed sensors. The goal of this study is to identify patterns that would deviate from the norms and could therefore, be used to predict adverse events.

"Smart homes" are typically individual dwellings that are equipped with networked sensor environments and embedded artificial intelligence, potentially supplemented by physiological measurements. With few exceptions, theses facilities are better suited to test sensors and devices rather than their effectiveness in terms of the quality of care and independence, unless the smart environments are actually retrofitted within the elders' residences.

Another example is the Ubiquitous Home real-life context aware test bed from National Institute of Information and Communications Technology of Japan [20]. WABOT-HOUSE Laboratory – A research institute founded by Waseda University and Gifu Prefecture, they focus on how robots can be part of a community and household to form a symbiotic society. The facilities include research laboratories as well as demo spaces for outdoor robotics and smart home technologies. [21]

Daiwa House D-Tec Plaza - A space where DAIWA HOUSE INDUSTRY CO. LTD displays new smart home technologies that may soon be seen in future homes. [22]

Nippon Telegraph & Telephone Corp. (NTT) is the main tele-communications group in Japan and is always searching for new ways to utilise ICT in healthcare. For example, employees of NTT, NTT East, and NTT DOCOMO are participating in a tele-counseling pilot to help monitor their health [23].

The system connects them a clinician with audio/video, as well as other sensors such as weight. Using these, the aim is maintain monitoring of patients, while reducing the number of routine doctor/hospital visits. Additionally, at NTT Data, they have started programs such as Japan Drug NETwork (JD-NET) [24], Health Data Bank [25], and the Creative Health SANKENJIN [26].

JD-NET is a system providing pharmaceutical companies with real-time information on the usage and needs of medical facilities. The Health Data Bank is a digital health records repository maintained by NTT Data for employees and others who wish to join the program, and the Creative Health SANKENJIN is a system that monitors exercise via a wearable body sensor, and then tabulates time spent exercising into “health service points” which can be monitored to help motivate the user.

See WBSN Chapter 5 for more details of monitoring system trials at this link.

7 KEY SENSOR NETWORKS INFRASTRUCTURE ISSUES

This section recaps on some of the major issues affecting reliable, robust and secure sensor networks. Issues here include

- Power consumption and techniques to preserve battery life.
- Adaptive and autonomic network management issues.
- Standards and Interoperability issues including Continua Alliance, IHE, HL7etc.
- Security and reliability of the sensor networks (‘Reliability Dilemma’).
- Network protocols such as Zigbee, Bluetooth etc.

Full details can be found on these topics in Chapter 5 Wireless Body Sensors

A further comprehensive review of these issues can be found in the CAPSIL Wiki at this link

8 DATA PROCESSING, ANALYSIS & INFERENCE

This section reviews a subset of the challenges of developing and deploying a reliable health monitoring network for independent living. The focus to this point has been on gathering data and in particular on the may type of sensors and sources available to perform particular sensing measurements (Movement, ECG, blood pressure etc).

Despite advances in sensor and monitoring techniques, the less obtrusive techniques are likely to be less reliable and noisier. This is due to the fact that the sensed phenomena are more remotely related to the quantity to be measured. In addition, sensing and inference needs to be performed with many sensors operating simultaneously, in a dynamic and mobile environment where the monitored quantities are changing continuously.

Last, but not least, the ultimate monitoring system must be resilient to changes in the environments, as well as to various failure modes of the sensors and the communication system. Effects of increased variability need to be mitigated by

1. Deployment of statistical signal processing techniques
2. Fusion of information from a variety of sensors.

These two approaches combined with quantitative models of the phenomenology enable computation of optimal estimates.

The key concept is that the inferences based on the raw data must be reliable and robust therefore the network must be capable of representing in an intelligible way the most appropriate inferences by managing itself in whatever way it has to achieve this.

Two key areas are Network Management and Estimation Techniques and Information Fusion and Querying Techniques.

8.1 Sensor Fusion

As noted above, one of the key principles in home and mobility monitoring is that the sensor systems must be as unobtrusive as possible. The cost of the unobtrusive approach is increased uncertainty and noise. The reason for the increased uncertainty is that unobtrusive sensors that are likely to be more distant from the measured phenomenon and are, therefore, subject to increased interference. In order to mitigate this problem, it is often necessary to deploy a number of "weak" sensors and combine their outputs at the inference stage.

In a nutshell, information fusion can be defined as the combination of multiple, conditionally independent sources to form more reliable and valid inferences. The information fusion process can aid in assessing not only the state of the monitored individual, but also the state of the sensor network. In particular, information fusion can be used in making location estimates of sensor nodes, detection of routing failures and collecting link statistics for routing protocols.

Information fusion has a long history, with applications ranging from target detection to medical diagnosis since the late 80's [32]. A particularly relevant definition of fusion was offered by Dasarathy [33] stating that "in the context of its usage in the society, it encompasses the theory, techniques and tools created and applied to exploit the synergy in the information acquired from multiple sources (sensor, databases, information gathered by humans, etc.) in such a way that the resulting decision or action is in some sense better (qualitatively or quantitatively, in terms of accuracy, robustness, etc.) than would be possible if any of these sources were used individually without such synergy exploitation." Of course, this definition is useful only to the extent that the "optimality" can be expressed quantitatively in the form of objective functions.

We note that fusion comprises methods of inference that combine statistical estimation approaches with techniques that enable transformation and alignment of signals from different sensors. Methods, techniques, and algorithms used to fuse data can be classified using a number of criteria, including the data abstraction level, purpose, parametric representation, type of data, and mathematical foundation. At the heart of most fusion techniques are inference methods.

8.2 Inference Methods and Context Awareness

Inference can be viewed as techniques for extracting information from raw data to answer specific question or evaluate specific hypothesis is the focus of inference methods. In contrast, estimation comprises a set of techniques that attempt to determine values of parameters of metrics.

Inference methods are required to provide inputs to rational decisions based on information derived from the sensor networks. More specifically, the best possible, "optimal" estimates of the states or parameter values can be used to drive "proactive" healthcare interventions.

In the context of home care, "Proactive healthcare" is concerned with learning "normal" patterns of daily activity and then determining any deviations from this "normal". When a deviation is detected, and the expected utility exceeds a given threshold an alarm can be raised and a corresponding action is taken such as contacting a caregiver. The concept is based on early detection of events and behaviours and proactive intervention. The proactive approach has been shown to avoid many acute medical conditions.

For example if a person normally visits the bathroom once per night and suddenly this goes to nine or ten times, it may indicate a serious bladder condition that if acted on early, may prevent a much more serious outcome.

An example of this may be found in 'Toms Story' in which the home monitoring systems realises that he is about to leave the house without having taken his medication.

The general approach to inference consists of formulating a quantitative model with a number of free parameters whose values are relevant to the phenomenon of interest. For example, one can assume that an elder walks with a constant velocity form one room to another. His gait velocity is the unknown parameter to be inferred from the set of observations comprised of sensor events that are triggered by his motion. Formally, inference yields "optimal" estimates of specific states or parameters.

The field of statistical inference is enormous since inference processes are the heart of most intelligent systems.

For convenience, we include a short list of the major current inference methods; more detail on each may be found on the CAPSIL Wiki.

Bayesian Inference.

Bayesian Inference is a class of algorithms, rooted in probability theory, that enable estimation of parameters that maximise the posterior probability of the observed events. Minimising errors is one objective function that has frequently been used within this framework, but depending on the severity of the possible outcomes it is possible to use expected utilities or similar criteria to be optimised. A Bayesian framework combines available prior information models of the specific observation processes and yields estimates of the posterior probabilities of the observed data. This principled approach has been used to solve many problems, including localization of nodes in mobile sensor networks [34], and also to detect and correct network and sensor faults [35]. It has also been used to optimise sensor networks in terms of power, routing and cost [36].

Dempster-Shafer Inference [37]

This Theory has been proposed to account for uncertainty in probability estimates: Estimates of probabilities are replaced by intervals. This theory then provides techniques for combining these intervals and can be used to fuse data from different types of sensors. Despite the intuitive appeal of the Dempster-Shafer theory, it has been difficult to find problems that could not be cast in a more rigorous probabilistic framework [38].

Fuzzy Logic [39].

Proposed to generalise probability in order to deal with approximate reasoning and to draw conclusions from imprecise premises. This generalization is not uniformly accepted and may lack the rigor of the theory of probability. In fact, it is difficult to find fuzzy-theoretic concepts that cannot be cast in probabilistic framework, where the membership function is replaced by probability distribution functions.

Neural Networks

The framework of neural networks can be viewed as a general language for a representation of nonlinear, adaptive systems. In fact, neural networks can implement arbitrary functions and dynamic algorithms that can be "trained" using a variety of training regimens. As such neural networks can, and often do, implement Bayesian inference processes. The terminology of neural networks was originally inspired by natural neural systems although this connection is rather tenuous. Although the generality of this framework has desirable properties, the implementation must be carried out with extreme care in order to assure that the resulting neural networks generalise properly.

Semantic Information Fusion

An in-network inference process, in which raw sensor data is processed so that nodes exchange only the resulting semantic interpretations.

The semantic abstraction allows a sensor network to optimise its resource utilisation when collecting, storing, and processing data. Semantic Information Fusion usually comprises two phases: knowledge base construction and pattern matching (inference).

The first phase (usually off-line) aggregates the most appropriate knowledge abstractions into semantic information, which is then used in the second phase (on-line), a pattern matching phase, for fusing relevant attributes and providing a semantic interpretation of sensor data. The idea is to integrate and convert sensor data into formal languages. The resulting language, obtained from the environment observations, is compared with the languages and known behaviours stored in a knowledge base. The idea behind this strategy is that behaviours or ontology's represented by similar formal languages are semantically similar.

State Estimation Methods

Estimation methods were adopted from statistical signal processing and control theory and use a probabilistic framework to estimate state of the system i.e. the state of the monitored individual.

State estimation techniques involve the development of quantitative models that define inputs, states, state-transitions and observable outputs. These models incorporate explicitly various sources of uncertainty at the input, state transition and observation levels. State estimation processes depend on the assumptions regarding the model embedding the system dynamics. The following are examples of approaches used for monitoring applications

Kalman Filter.

Now a classical technique for state estimation is based on the assumption of linear systems and Gaussian additive noise. It can be shown that, if the assumptions underlying Kalman filtering are valid, the approach provides the optimal state estimates in the least square sense. The block diagram of a Kalman filter is shown in figure 11. For a good treatment of Kalman filters see reference [40].

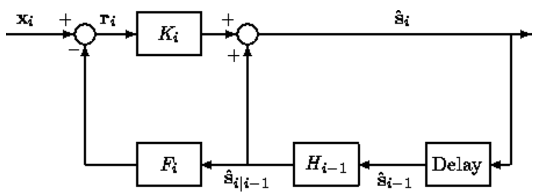

Figure 11. The Kalman Filter

In Sensor Networks, there are schemes to approximate distributed Kalman filtering, in which the solution is computed based on reaching an average consensus among sensor nodes. An important concern however is data loss due to the unreliable communication channels in sensor networks.

In this context, Sinopoli et al have shown [41] the performance of the Kalman filter in a scenario with intermittent observations and also shown the existence of a critical value beyond which the Kalman filter becomes unstable.

Another drawback regarding the use of a Kalman filter in sensor networks is that it requires proximate clock synchronisation among sensor nodes. Kalman filters have been used in algorithms for source localisation and tracking, especially in robotics. For a complete treatment of Kalman filters see [40,41].

Particle filters

Also known as Sequential Monte Carlo methods (SMC) are sophisticated model estimation techniques based on simulation. They are usually used to estimate Bayesian models and are the sequential ('on-line') analogue of Markov chain Monte Carlo (MCMC) batch methods and are often similar to importance sampling methods. If well-designed, particle filters can be much faster than MCMC. They are often an alternative to the Extended Kalman filter (EKF) or Unscented Kalman filter (UKF) with the advantage that, with sufficient samples, they approach the Bayesian optimal estimate, so they can be made more accurate than either the EKF or UKF.

The approaches can also be combined by using a version of the Kalman filter as a proposal distribution for the particle filter. A good treatment of particle filters in sensor networks is given in [42].

Sigma-Point Kalman Filtering

The current industry standard and most widely used algorithm for this purpose is the extended Kalman filter (EKF). Unfortunately, the EKF is based on a sub-optimal implementation of the recursive Bayesian estimation framework applied to Gaussian random variables. This can seriously affect the accuracy or even lead to divergence of the system. Rudolph van der Merwe and Eric A. Wan from Oregon Health and Science University have carried out extensive work [43, 44] in showing how sigma-point Kalman filtering (SPKF) filtering can retain higher order accuracy while maintaining complexity of the same level as EKF.

Other methods of estimation such as Maximum Likelihood, Least squares and moving average (weighted moving average) are commonly used in digital signal processing however in terms of sensor networks applications the main ones of interest are covered in summary here.

8.3 Presentation Level Information Fusion

Issues of data context and intelligent actions are becoming more and more important. In the next 20 years massive amounts of data from multiple sources across multiple domains will come together to form decision support systems that will then interpret the data and act accordingly. Technologies such as Web 2.0 are being mooted as possible platforms for such an integration and aggregation of disparate data sources, however much of this work is still in the research domain. The MIT M language [45] a Wiki based approach to developing a software solution to integrating multiple disparate data sources

In the meantime computational techniques such as Neural Networks can be used to 'learn' about systems and to give some context based on past information, input parameters, and probabilities.

More research is required into the intelligent fusion of multiple data sources to provide an accurate context within which a measurement is taken. It has been suggested that the development of sensors and hardware may outpace the development of the computational systems required to make proper use of the data. So a situation may arise where the data is available but there are no systems able to use it!

Key to informed decision-making is meaningful visualisation of information for the end user. Having access to historical information will allow the presentation of a current data set within a historical context and help to improve the accuracy of the decision-making. However the volume data even in processed format will present new challenges in the way data is presented to make it meaningful and to provide context. Visualisation will also help the healthcare community to understand health issues and health outcomes currently not possible with the current hospital orientated health models. See figure 12 for some examples of visual user interfaces.

Many of the data mining techniques which are applied in the retail, finance and manufacturing industries can be applied to the data sets from large scale assisted living technology deployments and will help to reveal patterns which can used to make meaningful changes in healthcare delivery. Of course maximum benefit of these deployments will only come when it is possible to integrate the data from the assisted living technology domain with GP and hospital records (assuming of course there digital patient records in place). 'Islands' of data with no connection or interoperability between them would significantly impact the value of any assisted living technology solution.

End to end integration of all data sets is absolutely critical and should form the cornerstone of national health policies.

8.4 Condition Monitoring of Sensor Devices

If wireless sensor networks are going to live up to their potential of providing improvements in wellbeing and health data, then a crucial question arises: How can a user trust the accuracy of information provided by the sensor network? Data integrity is vulnerable to both node and system failures. In data collection systems, faults are indicators that sensor nodes are not providing useful information.

In data fusion systems the consequences are more serious; the final outcome is easily affected by corrupted sensor measurements, and the problems are no longer visibly obvious. This question is applicable to all areas where wireless sensor networks are operational however in the health domain it is particularly critical, as this is a life or death domain.

W As discussed earlier and also as covered in detail in the WBSN CAPSIL there are many factors that affect the reliability of a sensor network including protocol used, power management, routing techniques, electromagnetic compatibility and environmental conditions. However, network reliability alone cannot be used to solve this problem because of uncertainties and the lack of control over the physical world and faulty nodes. Providing a reliable sensing channel is much harder than providing reliability over wireless radio channels because the sensor network designer only has control over the sensors receiver.

At the sensor level however i.e. beyond the transport and network level, issues that affect reliability include biocompatibility (sensor fouling, tissue damage etc), sensor-body interface, environmental interference and data quality issues.

Ganeriwal et al [46] has reported on the various mechanisms by which sensors fail and produce bad data, including the 'Sticky Values' idea where a sensor devices gets 'stuck' at a value and continues to output this bad data. Also included is the phenomenon whereby sensor data becomes unstable as battery nears end of life.

Just as in the human situation, wireless network systems need some form of system from which trustworthiness (or not) can be gleaned and decisions made based on this performance (judged from past performances). Reputation-based networks have been widely employed across many domains including e-commerce, Internet (eBay) and peer-to-peer networks.

However in contrast to internet based systems such as eBay, where the trust metrics are deterministic and act rationally, in distributed sensor network environments, the nodes can often behave irrationally and in a completely arbitrary manner.

Ganeriwal et al [46] have proposed a Reputation Based Framework for Sensor Networks (RFSN). RFSN borrows tools from Decision Theory, which assumes the nodes act randomly. Decision theory can be seen as the study of games against nature, where nature is an opponent that does not seek to gain the best payout, but rather acts randomly.

This general definition allows us to capture many possible node failures such as system faults, process noise, etc. Ganeriwal et al [46] has also noted that "the possibility of modelling this problem in the domain of Game theory should not be disregarded. There is a branch of game theory, non-cooperative game theory [Basar and Olsder 1999], which deals with exactly the same scenario of non-rational participating entities. It will be an interesting future challenge to explore, whether the same can be achieved using non-cooperative game theory…"

9 NON-TECHNICAL BARRIERS MONITORING SYSTEMS ADOPTION

There are many factors involved in the uptake of any new technology or service, some factors act against the uptake, others act in its favour. For home based healthcare factors that limit its uptake include issues of cost, complexity, perception and apprehension, privacy, broadband proliferation (lack of) and psychological factors. These are developed in the following section.

A Parks Associates report [47] stated that "The U.S.'s senior and baby boomer populations are not currently receptive to in-home health monitoring…" The same report concluded that, "two-thirds from both populations see little to no value in these services". According to the American Association of Retired Persons (AARP) "the older population has trouble adapting to technology because, there may or may not be actual ability to access the technology, cost can be a factor, and learning new skills can be difficult. Older adults also often find little of interest to convince them of the value of making the change, and very frequently, poor design makes technology products very hard to learn or use"

Some of the issues that hinder adoption of this technology will be developed more fully in the following sections.

9.1 Legislative Issues

Major issues within the legislative category, which have slowed the adoption of home monitoring technologies include security, privacy, licensing and jurisdictional issues, data ownership and accountability and the potential threats of litigation. These will be dealt with one by one.

9.2 Perception and Apprehension Issues

A 'digital divide' exists between people aged 38 to 59 age groups and people over 60 in their attitude and confidence in using technology. This is true not only of healthcare but to technology in general. However in healthcare, being a primal concern for most people, this divide is most pronounced. These psychological barriers need to be addressed if home health monitoring of seniors is to maximise its potential societal benefit. Issues such as proper (user friendly and intuitive) design of systems, guaranteed security features, personal health records and privacy legislation can help this cause greatly.

Research findings suggest that the use of remote home health monitoring equipment can lead to certain apprehensions in older patients who want to solely sustain their personal relationships with family and doctors.

Older patients may also resist using home health care monitoring services to avoid ceding authority to their adult children, who often gain more control over the health and lives of their parents with the introduction of monitoring systems. Some fears held by older adults are possibly a response to societal "ageism."

Society stigmatises signs of aging and weakness, which some older patients feel are enhanced through the public use of monitors. Another issue for older people will be the elimination of face-to-face care and this may create a perception that there will be a reduction of social interaction in the older person's life.

The lack of motivation in older people to use telemedicine in the home often may be due to an inability to understand how the technology will make dramatic improvements in quality of life. It has been suggested that one reason for this is that they are "present-oriented" and less willing to spend their time in an unpleasant way for a future goal.

For telemedicine to become a more widespread application, older adults need to adopt positive and imaginative perceptions and attitudes towards new technologies. This is the responsibility all concerned not just of older people themselves.

The technology needs to be user friendly and practical. How to set it up and use it must be almost transparent to the person’s daily routine, and finally the cost and reimbursement issues must be almost pervasive in nature and require very little bureaucracy and set up/sustaining time.

9.3 Privacy and Security

Home healthcare monitoring poses some fundamental problems in terms of security and privacy balanced with safe and effective healthcare. In reality these are two opposing ideas and the more effective the home healthcare package, the more threat to privacy that exists.

A major issue that comes up in this context is that of trust. “How do I know that others are not viewing my healthcare data without my explicit permission?” The Office for the Advancement of Telemedicine (OAT), identified consumer fears such as, “the presence of outsiders or non-clinical persons in teleconsultations, such as non-clinical technicians, camera people and schedulers located on either side of a telemedicine consultation or at the site of a service provider, either physically or via the technology they support. Clinical personnel who may not be visible or observable by the patient may also be involved in a teleconsultation. Patient information routinely stored electronically and/or physically at each site may not be protected by policies or procedures as effectively as information used in on-site encounters.”

The Internet is a primary medium for exchanging and storing health records and personal information of patients in telemedical applications. The Civic Research Report on Home Health Care Technology [48] states, “Currently, there are no standard protocols for protecting the security of email, telemetry, or electronic health records. Further, firewalls and encryption, while they may slow down the process, are unlikely to deter someone motivated to access personal health records. Wireless transmissions pose even greater concerns.

Concerns regarding privacy, confidentiality, and security of health information have always existed; however, the ease with which, the extent to which, and the context within which they may be breached are intensified with the electronic exchange of information.” Patients must feel safe from “nightmare scenarios,” which include accidentally transmitting medical information to the wrong address (or to someone masquerading as a physician) and allowing hackers to break into medical information that they then broadcast over the Internet.

Privacy concerns are more accentuated in older people as evidenced by a 2005 Pew Internet survey [49] which shows "61% of those 65 and older say they are 'very concerned' about businesses and people they don't know getting personal information about them or their families, compared to 46% of Americans between ages 18 and 29".

In Europe there are a number of policies that deal with privacy and security. Of particular relevance to telemedicine are:

- **Directive 95/46/EC** –"On the protection of individuals with regard to the processing of personal data and on the free movement of such data".
- **Directive 2000/31/EC** The e-Commerce Directive
- **Directive 2002/58/EC** – "Concerning processing of personal data and the protection of privacy in the electronic communications sector".
- **Directive 2005/36/EC** - Establishes the criteria for regulated professions according to which qualifications obtained in one member state are recognised by another.

Further details on Privacy and Security Policy in Europe can be found in the CAPSIL Wiki at this link

In the USA the applicable law regarding healthcare privacy is called The Health Insurance Portability and Accountability Act (HIPAA). The act is roughly broken in to two sections one of which protects health insurance coverage for workers and their families when they change or lose their jobs. The second, known as the Administrative Simplification (AS) provisions, requires the establishment of national standards for electronic health care transactions and national identifiers for providers, health insurance plans, and employers.

The Administration Simplification provisions also address the security and privacy of health data. The standards are meant to improve the efficiency and effectiveness of the nation's health care system by encouraging the widespread use of electronic data interchange in the US health care system.

In Japan there are many groups working on the policy involved with the utilzation of IT in healthcare, ranging from governmental agencies such as the Ministry of Health, Labor, and Welfare (MHLW) and the Ministry of Economy, Trade, and Industry (METI) to non-profit and research agencies, such as the Health Policy Institute of Japan (HPIJ). However, as of yet, there are no specific laws, only guidelines.

9.4 Policy Issues

A major issue in the uptake of home healthcare monitoring is that of policy variation between country, state and even sometimes at county level. Say for example a person is being monitored in France and the clinician resides in Germany; then the question arises – "which country's law is responsible for the integrity of the consultation (accurate, secure, private etc)? Where is the accountability and where is the enforcement if this contract is breached?"

The question of data ownership and jurisdiction (i.e. where is the medicine actually being practised?) is a major one that needs to be addressed worldwide. For example within the USA with the current licensing policies, it is impossible for a patient to seek care from a physician that does not practice in the patient's state. According to OAT "A patient in Oregon could not be treated remotely by a New York doctor, even if that physician were the country's foremost expert on the patient's disease." "This is detrimental to the patient's health because the individual might not receive the best care possible", and according to Intel's Eric Dishman, "it hinders telemedicine"

9.5 Cost and Reimbursement Issues

A recent Accenture report [50] noted that "Cost and complexity continue to hold back the development and adoption of converged digital home solutions". The survey findings indicate that more than three-quarters (80 percent) of consumers cite cost as the number one barrier to purchasing a digital home solution.

A 2004 Frost and Sullivan Report stated "Foremost among these [obstacles to telemonitoring growth] is the challenge of gaining reimbursement in a market perceived to be lacking the critical mass and evidence of cost-effectiveness. The absence of reimbursement impacts manufacturers investing in the innovation, adoption, and deployment of telehealth programs. While technology is a strong differentiator, industry participants realise that the prime driver of the market is reimbursement.

The home healthcare market is a subset of the digital home market and the evidence suggests that people in general are unwilling to invest in out-of-pocket home healthcare monitoring technologies at this time. A large part of this comes down to the lack of awareness of the benefits of the technology placed alongside the out-of-pocket costs of purchasing the technology.

As there no current reimbursement global strategies available from healthcare insurers, this is a cost that people are not willing to forego. Major progress on reimbursement, incentivisation and risk management is therefore needed and will probably be the single biggest factor in the adoption of home health monitoring solutions among older people.

Aside from the patient, there is also very little incentive for the healthcare providers to get involved in telemonitoring. Take for example a physicians practise with a busy staff and patient base. For the practise to get involved requires some form of out-of-pocket investment by the physicians (PCs, server, and software licenses etc). As there are no means of re-cooping this from insurers, the physician has to essentially take a risk on adoption of the technology. Also, if the physician misinterprets data from a telemonitoring patient, he will be sued with no insurance protection to fall back on.

So why should he/she take this risk? The logical position for them to take is to wait until all these issues have been ironed out and the proper policies, best-practices (and protection) in place

9.6 Policy and Reimbursements

It has been stated that reimbursement is important, because it encourages use of telemedicine services and removes a major barrier preventing its general uptake. This section will look at the USA, Europe and Japan and summarise the respective positions.

United States: In the US telemedicine reimbursements were first authorised in the Balanced Budget Act of 1997. From this it follows that Medicare (US healthcare provider) does reimburse some telemedicine applications but "this reimbursement only covers geographic areas with a shortage of health professionals," and is only for "teleconsultations provided in real time and does not make provision for store-and-forward consultations, in which information is gathered and stored for a physician to evaluate at a later time. This was improved upon in 2000 with the Benefits Improvement and Protection Act , which in essence increased the scope of eligible medical practices and eliminated the need for 'telepresenter' which was part of the 1997 act.

The assumption here has been that the service is being provider to a Healthcare Professional Shortage Area (HPSA) and the service is aimed at rural areas where clinical support is scarce.

In July 2008 the Medicare Improvements or Patients and

Providers Act [51] whose function was to further increase the scope of the Medicare coverage (including mental health and dialysis centres), passed both houses of Congress but on July 15th was vetoed by President Bush. However later that day, the Congress overrode the veto and the bill finally passed in to law. The law formally went in to effect on January 2009.

The 2008 Medicare Telehealth Enhancement Act, removes current geographic restrictions on the provision of such services. It also adds to the types of facilities authorised to participate in the telehealth program and directs the Secretary of Health and Human Services to encourage and facilitate the adoption of state reciprocity agreements for practitioner licensure in order to expedite the provision of telehealth services across state lines. The latest Major Action: 6/2/2008: on this bill is "Referred to House subcommittee on Health." Currently 35 states reimburse for Medicaid including:

Alabama, Alaska, Arizona, Arkansas, California, Colorado, Georgia, Hawaii, Illinois, Indiana, Iowa, Kansas, Kentucky, Louisiana, Maine, Michigan, Minnesota, Missouri, Montana, Nebraska, Nevada, North Carolina, North Dakota, Oklahoma, Oregon, South Carolina, South Dakota, Tennessee, Texas, Utah, Virginia, Washington, West Virginia, Wisconsin and Wyoming.

Less clarity is available on private payers and telehealth although some states in the US (California, Louisiana and Texas) do have legislation to cover reimbursement.

An excellent overview of the legislative situation in the USA is given on the American Telemedicine's Association website reference [52].

In Japan: thanks to the Nursing Care Insurance Law, under the Nation Health Insurance Plan coverage is provided for telehealth/ telecare services. However, funding for such services is decided depending on necessity and availability of funding, which is distributed to prefectural and city governments, who make the final determinations

In Europe: the picture is very fragmented with small scale pilots being the order of the day and little or no reimbursement policies or joined up thinking across countries. Recognising this is in 2008 the European Commission published a report [53] aimed at identifying the underlying issues preventing the adoption of telemedicine technologies and recommendations and actions to stimulate its adoption. It stated that "Despite the potential of telemedicine, its benefits and the technical maturity of the applications, the use of telemedicine services is still limited, and the market remains highly fragmented.

Although Member States have expressed their commitment to wider deployment of telemedicine, most telemedicine initiatives are no more than one-off, small-scale projects that are not integrated into healthcare systems". It goes on to say "Patients' compliance is high and some healthcare authorities have already acknowledged the need for these services.

Yet, most telemonitoring services are still limited to the status of temporary projects without clear prospects for wider use and proper integration into healthcare systems. Commitment by healthcare providers and concerted action between all stakeholders are needed in order to ensure wider deployment of these types of services throughout the EU". The report identified three key areas that action needs to happen to stimulate the telemedicine market:

Building confidence in and acceptance of telemedicine services

The Commission has identified that there is a clear lack of 'hard data' that quantifies the return on investment of telemedicine and telemonitoring. Many small-scale pilots have been carried out; however no large national pilot has been performed. The Commission's position is that until the data becomes available, insurers are unlikely to enter the fold and get creative around reimbursement policy. The Commission has agreed to publish a commonly agreed set of guidelines for telemedicine across Europe as well as fund through the Competitiveness and Innovation Framework (CIP) a large-scale telemonitoring pilot project.

Non-technical Barriers to adoption of monitoring Systems be found in the CAPSIL Wiki at this link.

Bringing legal clarity

The lack of legal clarity with regard to licensing, accreditation and registration of telemedicine services and professionals, liability, reimbursement and jurisdiction – is a major challenge for telemedicine. Cross border provision of telemedicine services require legal clarification with regard to privacy. Only a few Member States have clear legal frameworks enabling telemedicine. In some states, for a medical act to be legally recognised, the physical presence of the patient and the health professional in the same place is required; this is a clear obstacle to the use of telemedicine. In addition there can be limitations in administrative practice or law on reimbursement of telemedicine services.

The Commission has promised to support member states in the establishment of a Common European platform to support legal issues and generate policy regarding data flow, ownership and accountability within the EU thus enabling technical issues to be solved, while facilitating market development.

10 TECHNICAL BARRIERS TO MONITORING SYSTEMS ADOPTION

The EU has identified issues such as Broadband deployment and device interoperability as major issues needs to be addressed over the coming three years [53]. It proposes to support industry and other efforts aimed at overcoming these problems. CAPSIL notes that the same or very similar non-technical issues are barriers in US and Japan.

10.1 Personal Health Records (PHR)

The use of PHRs has been discussed extensively for years, with minimal traction and few if any real examples of adoption on a large scale. PHRs are proposed as an important tool for the gathering, collation and archiving of personal health information gathered within the home. A major attraction of the PHR is that it cedes control back to the patient (from the network or the administrator, clinician etc). A March 2009 [54] report identified renewed interest in PHRs and noted the positive effect on privacy, cost and security concerns. Availability of PHRs (such as Google Health) will be important factors in assisting the uptake of these new technologies in the home setting.

10.2 Broadband Proliferation

Broadband technology of whatever type (DSL, WiMAX, Satellite etc) is a key enabler technology for home healthcare monitoring, particularly if personal health records are to be employed. Many of the product offerings covered in section 5 show that the offering can work with an old fashioned modem dial-up (56kB) technology in a store-and-forward capacity, however this technology is not ideal for regular data forwarding or exchange of large files. Also to ensure privacy and security, the data packets may contain a lot of overhead and thus small packages may become very large and therefore slow to transmit. Access to a broadband is important for a home health package to maximise its potential. When broadband is discussed, three areas are key:

- **Speed** – At the end of 2004 the average DSL speed across the OECD was less than 2 Mbit/s. The average advertised speed of connections increased from 2 Mbit/s in 2004 to almost 9 Mbit/s in 2007. However the actual speed delivered to the customer can vary greatly and this has been an issue of some contention and has led to a lack of trust by consumers. This issue needs to be addressed going forward.
- **Cost** – Cost of a broadband service will be a key factor in the uptake of home health monitoring technologies

- **Coverage** - Since December 2004, broadband subscribers in the OECD have increased by 187%, reaching 221 million in June 2007 and 380 million in September 2008. Broadband is available to the majority of inhabitants even within the largest OECD countries. Some countries have reached 100% coverage with at least one wired broadband technology and up to 60% with coverage by two.

Broadband is viewed as an enabler for home healthcare and bearing in mind that the major cost items will be the hardware devices, software, monitoring etc, it is critical that broadband pricing remains very low. According to a recent OECD report between 2005 and 2006 the average price for a DSL connection fell by 19% and by 16% for cable Internet connections. Broadband is also affordable in most OECD countries. The price of a broadband subscription in 20 of the 30 OECD countries was less than 2% of monthly GDP per capita in October 2007.

In February 2004, the OECD Council adopted the Council on Broadband Development's Recommendations.

One Recommendation called on Member countries to implement a set of policy principles to assist expansion of broadband markets, to promote efficient & innovative supply arrangements, and encourage effective use of broadband services.

The Council instructed the Committee for Information, Computer & Communications Policy (ICCP) to monitor the development of broadband in the context of this Recommendation within three years of its adoption and regularly thereafter. Thus promoting the general ICT business, policy environment fostering ICT innovation (as well as ICT diffusion and use (including e-government) have been priorities. Likewise, ICT skills and employment, digital content and promoting trust have been key concerns. In particular, OECD governments have implemented demand-based approaches for spreading broadband access. Policy makers have made particular efforts connecting schools, libraries and other public institutions.

Overall, these policies have led to increased use of broadband across Europe. Governments have also fostered broadband content and applications, by acting as model users, promoting e-government services and broadband-related standards, by putting content online and by supporting development and distribution of digital content by other players. Regulatory measures have also put into place to promote a culture of security. On the consumer protection side there has been focus on developing awareness campaigns to educate consumers about Internet security risks and how to protect themselves against fraudulent practices

11 RESEARCH CHALLENGES

Regarding telehealthcare and telemonitoring there seems to be general consensus around its personal, and also its societal benefits. There is also a recognition that with the changing demographics of increasing population and people living longer smarter healthcare delivery models are required if healthcare provision is to be able to scale to match the baby boomer effect.

Telehealthcare is recognised as a development that could have a hugely positive impact on this very serious problem facing all healthcare providers. It has also been noted that despite large enthusiasm for the concept of telehealthcare, relatively little of any significance or scale has happened to date, despite the technology being available for quite some time. The underlying causes of these barriers must be dealt with if telehealthcare is to fulfil its true potential.

Much work is needed at the policy, and legislative level and issues of data ownership, accountability and privacy are paramount. From the technical point of view while remote monitoring devices have been available for quite some time, these devices need to be more intuitive, user-friendly and engineered with the end user in mind. In summary, areas that need to be address include;

11.1 Scalability

One of the most pressing problems preventing providers from embracing the ICT-based approaches concerns the ability of these systems to support remote care to a large number of individuals. Making such services available will require the development of infrastructure and platforms that would enable collection and real-time processing of large amounts of data.

The presentation of the resulting information will then be integrated within the workflow of formal and informal caregivers as well as healthcare professionals. Optimally, trials with subject samples exceeding 10,000 should be instigated. Such studies that would require collaborations between academia and industry would have to address issues ranging from installation to operation and maintenance.

11.2 New Generation of Sensors and Algorithms

Advances in technology will enable the development of improved data acquisition systems and techniques. It is critical to accompany these by the concomitant development of new data processing and inference algorithms. One of the challenges arises from the fact that a significant proportion of the monitoring data is event driven. This is in contrast to most of the existing data acquisition approaches based on uniform sampling techniques.

Another challenge is that due to the diversity of the monitored individuals, the dynamic nature of the environments the pattern recognition algorithms will have to be developed to detect unexpected, novel and rare events.

11.3 Reimbursements and Cost Mitigation

It is imperative that mechanisms are put in place to mitigate the cost of home monitoring solutions as data shows that people are not inclined to bear an out-of-pocket expense here. Healthcare insurers need to come on board with incentivisation programs and risk management schemes that motivate people to get involved. How to match telehealthcare with insurance premiums is a challenge and involves financial supply chains, modelling tools and risk management techniques. How to accurately charge for clinical time, how to ensure compliance to the program and how to share data across borders is indeed a challenge.

A major research effort around data ownership and accountability across borders is needed i.e. recommending policies and procedures that can be adopted by member countries and states. Unfortunately until these issues are addressed and involvement in a telemonitoring effort is 'made safe'; very little will happen area as fear of consequences (being sued) will always cause people to 'err on the side of safety' i.e. keep doing things the way they were always done.

11.4 Security and Privacy

Evidence shows that security and privacy are major concerns for people adopting telemonitoring solutions, particularly for older people. The idea of a person's confidential health information being accessible by parties other than those authorised, is a major concern. The inappropriate use of this data highlights one of the main concerns around pervasive technology in general, i.e. 'trust'. "How can I trust you when you tell me everything is secure and private..?"

It would be helpful here to conduct large-scale trials (at a national level) perhaps under a chronic conditions program (Diabetes for instance) where trust would be built up piece by piece. In fact, building up the profile of telehealthcare in this fashion is the only way that to engender this trust.

11.5 Perceptions and Attitudes

It has been reported that this is a bigger issue than might be imagined at first. The psychology of adoption of a telehealth solution needs to be examined very closely i.e. what does it mean for the person (particularly an older person)? Factors such as perceived loss of control, role reversal (with children for example), fears of social network decline, suspicions of the technology, fears of reduced privacy and user friendly technology are important here.

This work is complicated by demographics and ethnographic research, which can indicate what may work in Germany, may be culturally unacceptable in Turkey, or what would be acceptable in California may not be workable in Bulgaria. Thus this work will involve more ethnography, psychology and human-machine interface work.

11.6 Device Interoperability

Interoperability of devices and systems is being driven by various standards organisations such as The Continua Alliance. This work needs to continue further and be supported to its conclusion.

Currently, telemonitoring 'solutions' available operate proprietary networks. They are 'stove piped' to the extent that they don't (and cant) share data freely between different networks and health record systems. This needs to be changed.

The ideal scenario is completely compatible systems that can share data across networks and also across disparate medical record systems and databases. More work is needed around the PHR and its ability to share data across networks.

11.7 Technology Development

It has been pointed out that particularly among elderly people a mental barrier to technology exists and devices such as PCs and medical devices can be viewed as overly complex and not very user friendly. Design of the home monitoring devices need to be very user-centric and in fact should not resemble a computer device.

More effort in the human machine interface and in ethnographically informed device design is needed. User interfaces that enable clinical personnel to quickly learn the device are needed.

11.8 Development and Piloting of Body Sensor Network Systems

Ideally sensor devices should be pervasive and operate in the background with little or no human intervention. Body Sensor Networks offer huge potential in this regard and sensors woven into garments and furniture look quite promising.

There are of course a lot of challenges in developing these devices including practicality, reliability, robustness, bio-compatibility and usability and much further research is needed to bring these devices to market. There have been almost no pilots of any scale in the area of Body Worn Sensor networks for medical applications. This needs to be a focus area in to the future.

11.9 Broadband Proliferation

A more obvious area of focus is the area of Broadband proliferation. By proliferation it is meant 'affordable' broadband at reasonable quality and speed. This area is being primarily driven by the telecommunications industry however cost of provision still prohibits deployment in rural and remote areas.

Government policy needs to step in these cases to subsidise this deployment. It may even be a sound policy to provide free broadband to socially disadvantaged areas and for people with chronic conditions as the return of investment from the healthcare services provision would certainly outweigh the broadband costs involved.

11.10 Condition Monitoring of Sensor Nodes and Networks

Much further work is required also on the area of detection and correction of sensor node and network failures. For example the so called 'Sticky Values' problem that may be caused by a combination of sensor failure, sensor-skin interface or biocompatibility failure due to sensor–fouling.

Issues such as sensor de-tuning and attenuation near skin surface need to be understood further. Also biocompatibility interaction of sensors to human cells needs to be fully investigated.

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