Remote monitoring of health status of the elderly at home. A multidisciplinary project on aging at the University of New South Wales


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Abstract

This paper discusses the design and implementation of a multidisciplinary research project and associated field trials to test the hypothesis that functional health status amongst the elderly can be accurately determined remotely by continuously monitoring relatively simple parameters that measure the interaction between participants and their environment. In this study we propose that changes in such simple measures as mobility, sleep patterns, and utilisation of cooking, washing and toilet facilities, can identify changes in functional health status. One of the primary end goals of the project will be to automatically prompt appropriate, timely and cost-effective intervention of medical and community based services to help reduce morbidity and maintain an independent high quality of life for the elderly. Targeted intervention will diminish the demand for high cost medical services. This will have large potential economic implications in helping to contain and reduce the increasing cost of providing health care services to the aged.

Keywords: Remote monitoring; Telemedicine; Functional health status; Geriatric care; Computers

1. Introduction

The industrialised world is rapidly aging. In 1991, the Australian Bureau of Statistics (ABS) estimated 11% of the population was aged 65 years or older and 4.5% was aged 75 years or older. In the ensuing 20 years, the ABS anticipates growth in these age groups by 49% and 64%, respectively, during which time the total population will grow by only 29%. Overall, the number of dependent individuals in the community will increase substantially with respect to the working
population. The aged are also a high consumer of medical services. Relative to the economically active group in the age bracket of 45-64, the per-capita expenditure on health services in the UK increases by 278% in the age group 65-74, 563% in the age group 75-84 and 1034% for the age group over 85.

The morbidity patterns in the aged however are complex and difficult to manage. The transition from being an independent and relatively healthy individual to being sick, frail and often marginalised is often subtle and not easily perceived by patients and doctors alike. Older persons also respond to disease differently from younger adults. There are biological differences, so that usual symptoms are often not present and there may be a reduction in sensitivity and specificity of any one traditional symptom. In addition, multiple pathology is the rule rather than the exception. The end result of these factors is that an older person shows the presence of disease in total body responses and changes in overall levels of functioning.

The common presentations of disease in older people are reduced mobility, falling, confusion, incontinence, a longer time in bed and a general reduction in the usual tasks of self care and domestic care. Some older people, for social and psychological reasons, often seek to deny changes within their bodies, while others become confused, and so cannot perceive these changes. For these reasons, current health services often fail to help older people, who end up being isolated and vulnerable, and come to the attention of authorities only after a crisis.

There are two distinct populations of older people in any community. The healthy, energetic group, capable of accessing current health systems and being independent, and the sick frail group, who tend to be marginalised, hidden and finally 'dumped' into long term care. There is often a gradual transition between these two stages that is subtle and may not perceived by doctors and patients alike. Yet early intervention with appropriate medical, psychological and social therapies is able to reduce this progression to dependency.

Traditional methods of diagnosis fail to demonstrate this transition, and there is a need for methodologies that will provide objective and continuous assessments of an individual's function that can be applied to a person in their own home. Continuous, semi-automated monitoring of health status of the individual in the home may effectively intercept potential social, psychological and medical crises by automatically triggering an appropriate and timely response from local area health and community services or the client's doctor. Timely well targeted intervention, which helps to reduce morbidity and improve the quality of life, will diminish the demand for high cost medical services, and has large potential economic implications in helping to contain and reduce the increasing cost of providing health care services to the aged.

A substantial literature on methods and tools for the assessment of functional health status in the aged is available. A strong common theme evident in much of the literature reviewed, was that formal assessment methods are required both to ensure the delivery of appropriate health care support to the elderly and the disabled in the community and to be able to assess the outcomes of different interventions. There was also evidence of a rapidly evolving interest in the creative use of information, instrumentation and communications technology for the unconstrained monitoring of physiological and health variables at home. Evidence for this interest are major research programs in Europe, such as the Technology Initiative for Disabled and Elderly People (TIDE), and the European Prototype for Integrated Care (EPIC), initiated under the general umbrella of the Advanced Informatics in Medicine (AIM) program which has as a major theme the application of Telematics Systems in Health Care.

2. Measuring functional health status and functioning in the aged

A number of tools have been developed to measure functional health status and functioning. These provide a measure that can be used to assess and understand the impact of health problems on the daily lives of patients and to evaluate the effects of interventions. Both solitary, well
defined diseases and combinations of diseases can limit several aspects of function at the same time and lead to a range of effects on the person's life [1]. The most comprehensive and well documented are those recommended by the Royal College of Physicians and the British Geriatrics Society. These Standardised Assessment Scales for Elderly People [2] identify and select from assessment scales already available in the literature those which are most relevant to the needs of elderly people. The scales cover disability in everyday function, in communication, hearing and vision, and in cognition, along with assessment of mood, morale and social status. These assessment scales will be used in this research project to establish a baseline reference for clients participating in the study and will be repeated at the end of the trial to assess changes in health status that may have occurred during the study. The complexity and detail of these assessments however make them unsuitable for application on a weekly basis and alternative, simpler methods were investigated for this purpose.

Perhaps the best known of these are the Index of Activities of Daily Living and the Instrumental Activities of Daily Living (IADL) [3,4]. IADL assesses the degree of independence in basic tasks such as bathing, transfer, dressing, continence, toileting and feeding.

A set of functional status measures that has been developed for primary care and has been cross-culturally validated is the Dartmouth Coop Charts/WONCA. These are seven simple charts that assess physical fitness, emotional health, impact on social and daily activities, overall health, change in health and pain on a five item scale with representative diagrams. This has been validated against a number of other measures including the Sickness Impact Profile and the Rand/MOS health status measures [5,6].

Exercise is positively associated with other physical and emotional functioning and self rated health. This may be assessed as categorical or continuous variables by asking either whether a particular activity has been performed in the previous week or by asking its frequency and duration [7]. Sleep is another important aspect of functional status in the elderly. Measures have been developed which quantify the amount of sleep, the sleep pattern and the impact of sleep on feeling 'rested' [8]. While life satisfaction is not strictly a functional status measure it is useful in determining the subjective assessment of the well being especially in those with disabilities. The life satisfaction scale is a well-validated tool for assessing this [9]. In most cases self assessed ratings of physical functional capacity in the elderly is more accurate and less biased than ratings by informants such as carers and relatives [10]. However there is evidence that non-response and inconsistent response to self administered ratings increases with age [11].

3. Importance of functional status and monitoring for deterioration of function

There is a complex interplay between functional health status and physical disease, quality of life and social interaction and support. In most cases it is difficult to disentangle cause and effect [12]. Sleep is one aspect of functioning which has been demonstrated to be associated with a number of measures of well being including self perceived health status and life satisfaction [8]. It is in turn influenced by physical disease, psychotropic drug use, alcohol, depressive symptoms and social and recreational activity level.

There already exist a number of practical techniques for the unconstrained monitoring of physiological monitoring in daily life. Togawa et al. [13] reviewed these methods and suggested that most techniques can be accumulated automatically and unobtrusively using relatively simple technology. Lord and Colvin [14] reported on a simple subject-worn dosimeter which measured triaxial accelerations to detect and quantify falls within the home. Remote home monitoring of patient respiratory status via the telephone [15] has also been used successfully to manage elderly patients suffering from asthma. Inada et al. [16] reported on a home care support information system which can record and transmit a range of physiological measurements as well as data on symptoms and complaints. Other authors [17] have investigated the use of information technologies to provide support for persons living with AIDS/ARC in the
discuss a European approach to developing a health care information system, as a first step in the objectives of EPIC of providing technical and logistic organisation for a service of ambulatory and home ‘intelligent’ monitoring systems. In most of the developments reviewed monitoring is limited to the management of a specific range of medical problems and usually require the active cooperation of the subject.

The rationale for this study is therefore based on the following considerations:

- The increasing demands on the health care system as the population ages.
- The high cost of providing institutional care, and evidence that many problems associated with institutionalisation can be prevented if treated early.
- The importance of maintaining functional health status in the community.
- The increasing difficulty in monitoring health status of the elderly.
- The cost of regular home visits by health professionals (nurses, general practitioners).
- The difficulty in assessing functional status on a regular basis during routine visits (especially if the problems are only apparent at night).

4. Aims

The aims of this project are to investigate the relationship between remotely monitored measures of domestic, social and personal habits and a number of measures of functional health status of the elderly. Specific objectives are:

- To evaluate and validate the effectiveness and consequences of remote monitoring of health status of the elderly in the home on morbidity outcomes and quality of life.
- To develop data on key relationships between the living environment, psycho-social and socio-economic status and the development of morbidity patterns associated with the aging process.
- To evaluate the accuracy and reliability of the monitoring and communications technology in the household situation.
- To assess its acceptance and to deal with issues such as privacy and confidentiality of data.
- To identify which unobtrusively monitored measures or their combinations reliably and sensitively detect important changes in health status.
- To validate these measures and the algorithms to interpret them.

5. Methods

The project is being implemented as a collaborative multidisciplinary effort involving an engineering team of specialists in instrumentation, information and communications technology and a medical team of experts in community medicine and geriatrics. The engineering team is developing the instrumentation required for remote monitoring of environmental and behavioural parameters in the home. This technology is based on easily installed instruments which are powered by and communicate through the mains wiring in the house to a modem. Data is collected and preprocessed before being transmitted over the telephone line to a central base station for analysis and interpretation.

Sophisticated tools required to implement a major public health program and to manage and analyse the results of a complex field trial are also being developed. These tools include a centralised computer base station with the following facilities:

- A client and doctor registration system
- Facilities for the automated collection of monitoring data from participating clients via telephone modem
- Stock control facilities for the registration and location of remote monitoring instrument modules
- Security measures to ensure patient confidentiality and data integrity
- Import/export facilities for the transfer of data to and from handheld computers used in field interviews
- Standardised comprehensive client assessment scales for use at the start and end of each field trial
- Standardised health assessment instruments for weekly follow up and interview of clients.
The medical team is developing the interview instruments to be used for the weekly health assessments of clients participating in the study, and the selection criteria and induction procedures for the selection of clients. The medical team is responsible for the design and implementation of a small pilot project involving ten clients, and for all aspects of the design, implementation and management of two field trials to be carried out in the Waverly area of Sydney on two study groups each of 75 participants clients. These trials will involve instrumentation of homes, remote monitoring via telephone weekly health assessments by trained health care workers and data analysis using conventional statistical epidemiological methods as well as parametric and algorithmic methods derived from the disciplines of knowledge based systems and medical artificial intelligence.

A schematic diagram of the different components forming the telemedicine project for the remote monitoring of functional health status of the elderly at home is shown in Fig. 1.

6. Ethical issues and confidentiality of participant data

This project has major ethical implications and has been extensively reviewed and approved both by independent medical ethicists and by the Ethics committee of the University of New South Wales. Ethical issues of privacy however, only arise if data collected, no matter how sensitive, can be associated with a particular individual. We have implemented stringent safeguards to protect client privacy by providing password protected access to data strictly on a ‘need to know’ basis and by automatically de-identifying all accessible data using randomly allocated system identification (ID) codes. The Telemedicine database has in-built support for password protection using encryption. This facility enables all data stored in the various databases to be shared and viewed freely whilst rendering it unintelligible to any external viewers. Data can be viewed only when the session is initiated with the appropriate password.

7. The telemedicine platform

The telemedicine platform must support data collection activities from a number of sources. In addition to the basic requirements for participant registration and the recording of demographic and other data, experimental data is collected from four other sources:

- initial and final health assessment
- weekly interview (periodic on-going assessment)
- daily diary (self-reporting assessment)
- automated home monitoring and transmission via telephone.

To support these requirements we have developed a Microsoft Windows based user environment for:

- Managing the various practices, doctors and participants involved in the trial.
- Gathering and storing data received via modem from the home.
- Providing a seamless interface to other external processes. One process is the background modem link to the various homes involved in the trial. Another process is the Knowledge Based System (KBS) interface. The KBS will be used for analysis and interpretation of the remote monitoring data.
- Providing software support, including reports and diagnostics for the researchers involved in the trial.
Networking is supported by a built-in automatic locking mechanism. This mechanism is activated whenever data is to be modified and deactivated when the data is posted (updated or cancelled) thus imposing a transaction scheme. Furthermore directories can be mapped to aliases which are simply synonyms. Data can be protected by controlling access via passwords. The data is encrypted using a master password and access is controlled via auxiliary passwords. An auxiliary password is associated with one of five different access levels. These are Read Only, Update, Insert record, Insert & Delete record and ALL (includes deletion of the file itself). Fields within a record can be further protected by assigning a lower access level than that of the record.

8. Home monitoring sensor and communication technology

A key requirement of this project is the automatic collection of data from remote sensors operating continuously and unattended within the participants' home. A wide range of data needs to be collected from a number of different locations. The sensor instruments therefore needed to be low cost, easily retrofitted into an established home, and able to communicate back to a data collection point prior to transmission over the telephone line to a centralised basestation.

Cost considerations are paramount for widespread acceptance of this technology. The use of wire free communications between sensors/transducers and the control panel is thus an important factor in reducing installation costs. Power line communications systems may also be considered 'wire-less' as the mains power 'bus' is already in existence.

Following an exhaustive investigation of alternative technologies, we selected ECHELON as our development environment because of the sophistication of development tools available and the availability of integrated circuits for mains frequency signalling. These are miniature circuit card or encapsulated modules containing ECHELON'S direct sequence spread spectrum integrated circuit, crystal oscillator, receive front end transmitter amplifier and filter, power line communication coupling circuit. Neuron 3150 CHIP, PROM socket and switching power supply that supports both on-board power as well as supplying off-board application power. A data rate of 10 Kbaud is supported in the frequency band of 100–450 kHz. Hardware development is supported by the LonBuilder Developer's Workbench. This is an IBM PC-compatible based host program that enables design and debugging of LonWorks nodes within a Neuron emulator.

The Neuron C programming language provides a high level of software design support for the Echelon LonBuilder development station. Neuron C is based on ANSI C, but contains extensions such as:

- Event driven code through the when statement e.g. 'when event do task'
- Access to millisecond and second timer objects.
- Immediate access to 11 input/output (I/O) pins of a Neuron chip through many different I/O objects
- Network variables and explicit messages (which allow nodes to communicate with each other).
- A built in main library of I/O drivers and a communications protocol in on-chip ROM.

The three CPUs within the Neuron chip thus provide all the elements necessary to implement a Local Operating Network (LON). In our project a LON consists of three Multi Input Sensor Controller (MISC) unit's (described in the following section) and a PC connected to the Public Switched Telephone Network (PSTN) as shown in Fig. 2.
9. Development of sensor technology

Various analog and digital sensors were considered, these include:

- Infra Red sensor (IRS), similar to those used in security systems
- Light sensor (LS)
- Temperature sensor (TS)
- Mechanical switches
- Magnetic switches
- Central power sensor
- Appliance power sensor (wound over the appliance’s power cord)
- Pressure sensor (various kinds of mats)
- Sound sensor (based on automatic recognition).

The first five sensors shown in the list were selected as offering the greatest cost benefit and flexibility. Each of these can be used in a number of modalities as indicated below.

9.1. IR sensors

- broad beam to detect presence and calculate mobility
- narrow beam to target specific areas such as doors and beds.

9.2. Light sensors

- to detect night/day/bed to detect switching on/off of lights.

9.3. Temperature sensors

- to measure ambient temperature
- to detect use of shower
- to detect water flow, such as in toilet flushing
- to detect use of electrical appliances

9.4. Mechanical or magnetic switches

- as alarm buttons
- to measure mobility by identifying opening and closing of doors
- to identify use of major appliances such as the refrigerator.

Combinations of these sensors together with relatively simple logic can be used to characterise even very complex sequences of activities.

A plug in instrumentation module capable of accepting a range of sensors and communicating via the mains wiring has been developed, based on the Echelon Neuron Chip and PLT-10 Transceiver. This MISC module was designed to support:

- Mains communication using the LonWorks protocol
- Four (4) Analog devices
- Four (4) Digital devices
- Serial RS232 communication.

A schematic diagram of the MISC is shown in Fig. 3.

The MISC modules communicate over the mains power lines and transmit data to a local low cost personal computer via a serial port. Data is collected, processed locally and transmitted in encrypted form to the telemedicine basestation at night using a low cost dial-up internal modem. An emergency capability is also available which can be activated either by pressing an alarm button on each MISC or by the automatic identification of possible emergencies using a simple rule based algorithm which seeks to detect unexplained cessation of activity. Receipt of an alarm condition will result in automatic dialling of a paging service which alerts either a 24 h emergency service or a designated member of the medical team.

10. Current status of the project

Implementation of the project has involved a number of discrete phases.

Fig. 3. Schematic layout of the Multi Input Sensor Controller (MISC).
10.1. Preparation phase

During the initial preparation phase which is now complete, the client registration system, remote monitoring device, project protocols and health assessment instruments were developed and tested and qualitative data was gathered by conducting a focus group with elderly outpatients.

10.2. Pilot project

This second phase aims to assess the procedures for the selection and recruitment of candidates, the obtaining of informed consent and to evaluate the acceptability of the home monitoring and the health visits. Ten sites will be equipped with the remote devices systems and monitored for ten weeks. The pilot project begins in July of 1995.

10.3. Field trial

The third phase is the field trial which is scheduled to commence in late 1995 and will involve two groups of participants; one of moderate dependency from the day care facility at the Waverly Memorial Hospital in Sydney and one group recruited from general practice. Seventy five participants each will be randomly selected from registers of patients drawn up from the Hospital and the 25 General Practitioners (GPs). People aged over 65 years who live alone will be eligible. Participants will be screened according to an initial health assessment, those with symptoms or signs of dementia will be excluded.

After induction the field trial participants will be visited on a regular weekly basis for the first three month period. These assessment visits will use a number of instruments:

- The DUKE Health Profile. A 17 item instrument which measures health along the three major WHO dimensions: physical mental and social well being. Dysfunction is indicated by separate measure for anxiety, depression, pain and disability. A strong point of the DUKE is that it includes items for cognition, social self-esteem, confinement and somatic symptoms other than pain, which are not included in the COOP/WONCA charts.

Both these measures have the advantage of being brief and able to be administered on a regular basis. They will be supplemented with questions about illness episodes restricting their physical activities or causing them to stay in bed, and their use of medications, hospitals, GPs or other health services in the preceding week.

The data from each home visit will be recorded on site using a palmtop computer. Data will be downloaded to the project database on a daily basis. Because of the possibility of a Hawthorne effect of the visits themselves on the health status of the participants, the monitoring will be continued for a further three month period without home visits.

Participants will also be asked to keep a daily diary which will record any significant symptoms and health events as well as changes in behaviour. This diary will enable closer correlation with remotely monitored data and will reduce recall bias by providing daily information to match with the weekly visits.

11. Conclusions

While many aspects of this multidisciplinary project are still under development, the core technology, including the telemedicine platform and sensor modules have been designed and tested. Likewise the key instruments for assessing health status in the elderly have been selected and implemented in computer form. After completion of the field trial we will have created a unique database of health assessment versus functional status. A key challenge for the future will be the creation of a knowledge based system to analyse and interpret this data.
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References


