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**FULL TITLE: A SYSTEMATIC REVIEW OF LIFESTYLE MONITORING TECHNOLOGIES**

**SHORT TITLE: LIFETSYLE MONITORING SYSTEMATIC REVIEW**

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**ABSTRACT**

Lifestyle, or behavioural monitoring is an important element of telecare research where changes in activity profiles are used as a proxy to highlight a change in an individual's health or care status. However, despite the promise of this approach for users and care providers it has been slow to develop. A literature review was undertaken to establish the current position with regard to lifestyle monitoring and to use this to inform requirements for the future development and implementation of such systems. In total, 74 papers met the inclusion criteria. Only 4 papers reported trials involving 20 or more individuals with a further 17 papers reporting trials involving one or more individuals. Most papers (n=53) were concerned with technology development initiatives. With respect to the technologies and strategies employed, motion monitoring dominated, followed by door and electrical appliance usage. The predominant monitoring strategy is that of detecting changes in activity levels. However, it was noticeable that little attention was given to determining when or how changes in the profile of activity should be used to raise a call for assistance from a health or care professional.

## INTRODUCTION

The greater emphasis on delivering health and care to people in their own homes has been a priority for some time. In 2002, the World Health Organization (WHO) commented that "*as long as the acute care model dominates health care systems, health care expenditures will continue to escalate, but improvements in populations' health status will not."* [1] In 2009, the European report 'Dealing with the impact of an ageing population in the EU' [2] commented that "*In order to limit the expected increase in public expenditure, policy measures which can either reduce disability, limit the need for formal care amongst elderly citizens with disabilities, favour formal care provision at home rather than in institutions or, more generally, improve the cost-effectiveness of long-term care provision, e.g. through introduction of eHealth and telecare must be developed*."

Lifestyle monitoring, or as it is sometimes called behavioural monitoring, forms a sub-set within the wider and more general model of telecare. Sensors are installed around the home and behaviour monitored in order to gain an understanding of 'normal' activity such that any changes over time can be recognised as unusual and be responded to. For example, a sudden change in mobility around the home may indicate someone has fallen, or a gradual decline in time spent in the kitchen may suggest illness or malnutrition. Additionally, some applications of lifestyle monitoring are being deployed as assessment tools, where they are installed for a short period of time to provide additional and reliable data to help inform the care assessment process[3].

Overall, lifestyle monitoring systems potentially offer a new mechanism for ensuring a safe environment for older and vulnerable people to remain at home with the reassurance that, if unforeseen events occur, assistance can be provided in a timely manner.

The underlying assumptions of lifestyle monitoring, namely that it is possible to determine an individual's health or care status by the remote monitoring of behavioural characteristics were the focus of the study undertaken by Celler *et al* [4] in 1995. They concluded that an individual's health status could be determined by remotely monitoring relatively simple parameters relating to the interaction between the individual and their local environment. They reported that some 50% of individuals had undiagnosed medical problems that could be detected by home monitoring. This foundation was built upon by Anchor Trust and British Telecom who developed a system to detect changes in a users lifestyle [5,6]. The final conclusions of these studies were that the system was generally acceptable, that it enhanced feelings of safety and security, that it increased care choices, and that it supported and enhanced the carer's role.

Despite the growing interest in all aspects of telecare, the formal evidence base, especially for lifestyle monitoring, remains relatively weak despite there being significant numbers of commercial installations around the world. A literature review was therefore undertaken to establish the current position with regard to lifestyle monitoring with distributed sensors within the home and hence to use this to inform requirements for the future development and implementation of such systems.

## METHODOLOGY

The review considered articles dealing with lifestyle monitoring available on the electronic databases OvidSP (and including Medline, CINAHL, PsychInfo and British Nursing Index) and INSPEC using the search structures and terms set out in Table 1. All articles, including conference proceedings, published in the English language between January 1990 (5 years before the Celler study which is arguably one of the first of its type) and December 2009 were included.

Table 1: *Search terms and search structure*

| Search | Keywords |
|---|---|
| **1** | Activity of Daily Living or Activities of Daily Living or ADL or Lifestyle Reassurance or Lifestyle Monitoring or Home Monitoring or Assisted Living or Activity Monitoring or Behaviour or Behavior or Behavioural monitoring or Behavioral Monitoring or Ambient Intelligence or Smart Home or Smart Dwelling or Domotics or Gerontology or Home Automation or Ambient Assisted Living or Ambient Assisted Environment |
| **2** | Assistive Technology or Assistive Technologies or Telecare or Tele-care or Telehealth or Tele-health or Telemedicine or telehomecare or tele-medicine or tele-homecare or home health monitoring or ehealth or e-health or vital signs monitoring or vital-signs monitoring or vital signs or vital-signs |
| **3** | 1 AND 2 |
| **4** | As Search 3 but limited to the interval 1990 to 2009 |

The focus of the review was on home based lifestyle monitoring systems using the following the exclusion criteria:

- Articles evaluating user views only
- Articles of Smart homes centred around the control of the environment only
- Behavioural monitoring using mobile systems such as GPS or mobile phones
- General reviews of assistive technology
- Horizon scanning or 'blue sky thinking' articles
- Non journal or conference proceedings
- Not written in English
- Stand alone technologies related to vital signs monitoring with no links to the identification of behavioural change
- Technological concepts with no evidence of development
- Technology centred around the use of video cameras only
- Technology centred around the use of wearable sensors only
- Theses

No exclusion criteria were set on the quality of papers.

Two reviewers independently applied these criteria to the papers identified. In the case of any disagreement, a third, independent reviewer had the final decision on which papers were included. The exclusion criteria were then applied again on the full papers and, where appropriate, data extracted. It should however be noted that a number of papers deployed distributed sensors for behavioural monitoring in association with vital signs monitoring, video cameras and worn sensors and these were retained in the review.

**Results**

The database search identified a total of 1,994 articles. Of these, 1,420 were associated with OvidSP and its subsidiary databases and 574 with INSPEC. On review, it was established that there were a total of 159 duplicates between the databases, giving a total of 1,835 unique articles.

The initial screening of these 1,835 articles resulted in a total of 133 potentially relevant articles, with the two reviewers agreeing on 79 (59.4%) of these. The remaining 54 articles identified by only one of the reviewers were then independently evaluated by a third reviewer and it was decided that 28 of these articles should be included and 26 excluded. This resulted in 107 articles being carried forward to a detailed review of the full texts. Of these, a further 15 were rejected on the basis of the full text while 18 proved to be unobtainable even when the authors were contacted by mail and email, leaving a total of 74 articles to be subjected to full review. The distribution of these 74 articles by year is shown in Fig. 1. The first paper included in the review dated back to 1997, indicating that Celler's study of 1995 could be considered as one of the earliest of this type.

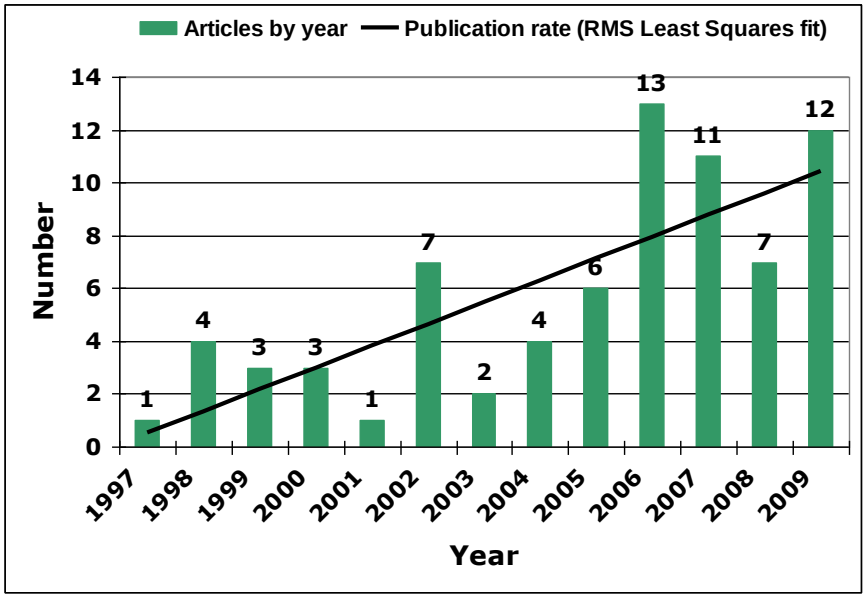


Figure 1: *Number of publications identified for review by year of publication*

Of the 74 full articles reviewed, only the 4 [7,8,9,10] shown in Table 2 were concerned with trials involving over 20 subjects whilst a further 21 papers reported trials with fewer than 20 subjects. The full distribution of reported trials is then as shown in Fig. 2. The remaining 49 papers then described only technology development without reporting on any formal user trials.

Table 2: *Articles reporting trials involving more than 20 participants and sorted according to sample size*

| Lead Author | Sample size | Technologies | Monitoring strategy |
|---|---|---|---|
| Barnes | 40 subjects for 6 months | PIR, magnetic (reed) switches, temperature sensor | ADL and activity data |
| Brownsell | 24 subjects + 28 subjects in a control group for 12 months | PIR, door, flood, fall, chair & bed occupancy, electrical usage, extreme temperature (cooker) | General levels of activity, including nutrition. |
| Sixsmith | 22 subjects at 4 locations | PIR, contact sensors, room temperature sensors | ADL |
| Alwan | 22 subjects | PIR, temperature sensor (cooker), bed occupancy, passive floor-vibration based gait monitor, fall detector (underneath the bed), physiological parameters (heart rate, breathing rate, and gait) | ADL, key alert conditions such as falls |

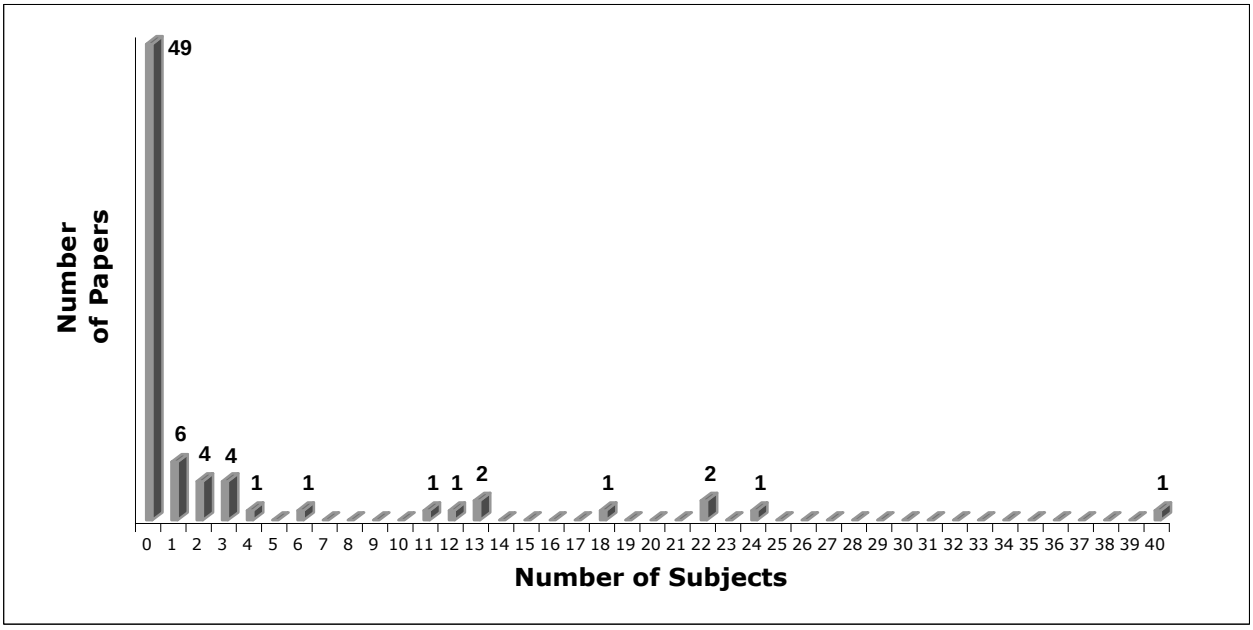


Figure 2: *Distribution of papers and subjects*

In terms of the technologies being utilised in the studies, motion detection was the most commonly used form as highlighted in Table 3. For studies which included other monitoring approaches in addition to behavioural monitoring, Table 4 lists the other sensor types used. The number of studies employing associated monitoring strategies is shown in Table 5 whilst Table 6 shows additional information associated with the deployment of the monitoring approaches of Table 4.

Table 3: *Number of studies employing specific distributed sensor types*

| Technology/Sensed Parameter | Occurrences |
|---|---|
| Motion Detection | 30 |
| Door open/close | 13 |
| Electrical appliance use | 9 |
| Fall | 8 |
| Bed/Chair occupancy | 6 |
| RFID – Location, device use, etc | 6 |
| Ambient temperature | 6 |
| $CO_2$ | 3 |
| Drawer open/close | 2 |
| Lights | 2 |
| Pressure pads | 2 |
| Sink usage | 2 |
| Smoke/Flame detector | 2 |
| Touch | 2 |
| Bath usage | 1 |
| Flood | 1 |
| Gas sensor | 1 |
| Humidity | 1 |
| iMOTES | 1 |
| Presence | 1 |
| TV usage | 1 |

Table 4: *Other forms of monitoring used in association with a behavioural monitoring approach as the primary element*

| Technology/Sensed Parameter | |
|---|---|
| Accelerometers | 5 |
| Vital signs/Physiological | 5 |
| Video | 4 |
| Blood pressure | 3 |
| Heart | 3 |
| Body area network | 2 |
| GPS | 2 |
| Gait | 1 |
| Smart clothes | 1 |

| | |
|---|---|
| Speed of movement | 1 |
| Telephone | 1 |
| Tilt | 1 |
| Weight | 1 |

Table 5: *Parameters evaluated during behavioural monitoring*

| **Parameter** | **Occurrences** |
|---|---|
| Activities of Daily Living (ADL) | 23 |
| General level of activity[1] | 12 |
| Sleep/wake relationship | 3 |
| Agitation | 2 |
| Behavioural monitoring | 2 |
| Nutrition | 2 |
| Time spent in a specific space or spaces | 2 |
| Conceptual model of quality of life | 1 |
| Periods of immobility/inactivity | 2 |
| Location tracking | 1 |
| Satisfaction with Life Scale | 1 |
| Social interaction | 1 |
| Social interaction monitoring | 1 |
| TV use as an indicator of well being | 1 |

Table 6: *Parameters evaluated in association with behavioural monitoring*

| **Monitored Parameter** | **Occurrences** |
|---|---|
| Ambulatory monitoring | 5 |
| Agitation | 2 |
| Speed of motion | 2 |
| Mobility | 1 |
| Distance travelled per day | 1 |
| Human capability monitoring | 1 |
| Location tracking | 1 |
| Personal energy expenditure | 1 |
| Physiological monitoring | 1 |

Table 7 presents the information analysis, artificial intelligence and machine intelligence approaches and strategies used in those systems which have taken this approach. However, despite the increasing investigation into such techniques, they are, on the basis of the papers reviewed, essentially aimed at the evaluation of the potential for AI rather than as fully operational and robust solutions with measurable performance data to support deployment.

Table 7: *Information analysis and artificial intelligence methods deployed*

| **Methods** | |
|---|---|
| Ambient intelligence | 6 |
| Bayesian/statistical methods | 5 |
| Fuzzy methods | 2 |
| Support Vector Machine | 2 |
| Data mining | 1 |
| Event clustering | 1 |
| Fast Fourier Transforms | 1 |
| Neural networks | 1 |
| Pattern recognition | 1 |
| State models | 1 |

[1] A distinction is made here between those monitoring systems which use a formal means such as the official Barthel index to record ADL and those which express general levels of activity by other means, as for instance the proportion of active time in a day or transitions between rooms.

## DISCUSSION

The majority of articles provided only an overview of the methods that were applied along with, where appropriate, brief details of the evaluations being undertaken. It therefore becomes very difficult to obtain a complete understanding of what systems and methods are being deployed and in what context. Without the requisite clarity to understand and appreciate the nature of the interventions being proposed, the value of these papers to the wider academic community is substantially reduced. There is therefore a need for all involved in the reporting of research and development findings in this area to be more transparent regarding what they are seeking to achieve and the associated processes and methodologies being deployed. Without this clarity, already known issues and problems will be repeatedly encountered by others, increasing the time required to develop and evaluate appropriate lifestyle monitoring systems with a true potential to provide help and support to service users, family members and service providers.

Fig. 1 suggests there has been a gradual increase in publications on lifestyle monitoring in the home since 1997. However, only 25 papers report trials involving 1 or more individuals with 49 papers reporting on technical development in the absence of trails. This provides only weak formal evidence to support deployment, despite numerous commercial installations around the world. Where evaluation with users has taken place, the literature focuses on case studies and has not yet addressed the clinical and cost effectiveness of the intervention when compared to traditional health and care approaches. Large scale and longitudinal studies would be beneficial, such as that being undertaken by Kaye who has recruited 200 older people, installed lifestyle monitoring systems in their homes, and is currently gathering data over a 30 month period [11].

Many commercial lifestyle monitoring products are now offered for short term health and care assessments [12, 13], where systems are installed for a period of a few weeks and are then removed. From a research perspective, our review suggests that the focus has been on long-term monitoring of changes in behaviour and not a one-off short term assessment. Given that there may be more of an immediate commercial market in short-term care assessment, researchers may find it valuable, in order to maximise the impact of their research, to focus their efforts on short-term assessments as well as long-term monitoring.

Referring to Tables 3 to 7, it can be seen that a wide range of sensor technologies are being deployed and operating in association with an equally wide range of monitoring strategies. For most approaches though, the prime sensor technology remains the PIR for motion detection, followed by door contacts and electrical supply monitoring. These are established technologies which may however have limitations in lifestyle monitoring applications. For example, incorrectly positioned PIRs can result in blind spots or simultaneous activation in multiple rooms whilst spurious data can occur as a result of external factors such as the movement of curtains. The sleep modes used for battery saving can reduce the data captured and there is generally no provision for distinction between multiple individuals in a single dwelling.

Such limitations can reduce the quality of the monitored data, and subsequently the sensitivity of the algorithms deployed in a lifestyle monitoring system. These somewhat crude sensors for data capture may be appropriate for monitoring very high level changes in room occupancy and so forth, but for finer analysis the resolution may well be too low. Thus when attempting to link user activity data to formal health and care assessment, researchers may need to acquire finer granularity data to ensure that accurate assessments can be made.

With respect to the monitoring strategies being employed, it is clear from Table 5 that the predominant monitoring strategy is that of detecting changes in activity. However, it was noticeable that while data gathering and analysis primarily focuses on this, very little attention has been given to determining when or how changes in the profile of activity should be used to indicate an important change in health or care status that merits the raising of an alert. Thus, the emphasis has been on detecting changes in and to the profile of activity, but not on linking this to procedures to determine health and care needs, or of triggering a re-assessment of such needs. Indeed, in many instances there appeared to be a deliberate decision that the focus should be on highlighting changes to activity profiles, and that professionals should then analyse the data and determine when and how to intervene.

While this reduces the technical complexity, it could be suggested that until automated systems are in place this will be a barrier to uptake. Specifically, it is unlikely to be a cost effective system if clinicians have to spend time large amounts of time looking at changes in behaviour that subsequently does not necessitate a health or social care intervention.

In support of the interpretation of the source data, a significant number of the articles reviewed considered the deployment of a range of information analysis, artificial intelligence and machine intelligence strategies as a means of identifying changes in patterns of behaviour. However, where such methods were deployed, these were generally structured within the context of an established profile of behaviour with limited attention given to the introduction of

other, long-term, factors which may influence behaviour, as for instance seasonal variations in behaviour. It should also be noted that much of what was reported with regard to the deployment of such methods was associated with the evaluation of the method rather than its deployment in a 'real' environment.

A number of questions are therefore raised by the analysis of the lifestyle monitoring literature:

1. What is the primary purpose and role of lifestyle monitoring (assessment, long term monitoring or both)?
2. Can levels of activity be effectively monitored using sensors as currently deployed?
3. Is the link between health status and activity sufficiently well understood?
4. What features of a particular person's life and activity should be monitored?
5. Do the data analysis techniques being utilised actually result in clinically important information?
6. What is the requisite service response to monitoring, and what are the organisational and operational issues associated with this?

## CONCLUSIONS

The original aim of the literature review was to establish the current position with regard to lifestyle monitoring research and hence to inform requirements for future development of such systems. Whilst the review has provided increased clarity of understanding of the research profile and activity worldwide with respect to lifestyle monitoring, the lack of detail as to both methods and outcomes has meant that it has not proved possible to build the outcomes into an increased understanding of future requirements in any formal way. Rather, although there are some promising and exciting case study results, overall the review suggests that lifestyle monitoring remains a relatively immature research area in which there is little detailed understanding of how to provide comprehensive and effective systems.

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Full details of the references included in this literature review can be obtained from the author.

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