Proceedings of the 28th IEEE
EMBS Annual International Conference
New York City, USA, Aug 30-Sept 3, 2006

Optimum Design of Remote Patient Monitoring Systems

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Abstract— **Remote patient monitoring (RPM) of physiological measurements offers the potential to provide high quality care to elderly, chronically and acutely ill people in their home environment, while making effective use of healthcare resources. However, despite its clearly demonstrated potential, RPM has not become an integrated part of patient care so far. In this paper, we undertake an extensive systematic literature review to identify the typical set-up of RPM projects and services in the UK. We then propose a solution for a clinically and organizationally more integrated service, which is based in primary care. Key to the design is the involvement of other healthcare services such as social care, the emergency department of a hospital, and out-of-hours General Practitioner services, and also the involvement of the patient and their carer/s. This allows a team-based approach with information-sharing across different healthcare sectors, and offers maximum continuity of care for the patient.**

Keywords—**Remote patient monitoring, telemonitoring, integration, sustainability, design, physiological measurements.**

I. Introduction

The increase in the proportion of elderly people in society [1], a group which frequently suffers from chronic disease and consumes a high level of healthcare resources, requires a highly effective and efficient provision of care, if expenses are to be contained. Remote Patient Monitoring (RPM) offers the potential to provide high quality care to elderly, chronically and acutely ill people in their home environment. It entails the electronic monitoring of physiological measurements in a setting other than a hospital, such as a patient's home, or in a communal setting such as a residential or nursing home, using information and communications technologies to transfer data over geographical distances [2]. .Heart rate, blood pressure, ECG, SpO_2, temperature and respiration are commonly seen as the vital signs. Glucose and weight are also used for monitoring long-term conditions. RPM is also known under terms such as "telecare", "telemonitoring" and "home monitoring", although "telecare" is also used to refer to social alarms.

RPM is believed to be more convenient and cost-effective than traditional institutional care, since it enables patients to remain in their usual environment whilst being looked after professionally. Remote patient monitoring can provide an alternative to hospital monitoring, as it can facilitate early discharge of patients from hospital, or as a substitute for hospital care. It can also help to identify hospitalisations by detecting deterioration early. This can reduce the number of unnecessary admissions and enable prompt emergency admissions [3]. In addition, it can allow healthcare professionals to manage a greater number of patients with long-term conditions, since they are able do so from their offices (see e.g. [4]).

In a move to prepare the health service for these challenges, the UK government aims to make telecare available to all homes requiring it by 2010 [5]. It is hoped that this will allow elderly and disabled people to live independently for longer, and so prevent or postpone their institutionalised care [5].

However, despite efforts from the government, the health service, industry and academia, RPM uptake in clinical practice has been slow (e.g. [6,7]). The authors argue that this is mainly due to a lack of integration into the healthcare service (see also [6]), clinically, as well as organisationally and technically. In this paper, we have investigated RPM projects and services in order to identify the features, and so describe the typical architecture. We use this to determine the extent to which it is integrated into existing health services. We then propose a more integrated a solution.

II. Methodology

We searched the following databases to identify RPM projects and services: the Foundation for Assistive Technology (FAST) [8], the UK Telemedicine and E-health Information Service (TEIS) [9], the Telemedicine Information Exchange (TIE) [10], Integrating Community Equipment Services (ICES) [11], and the European Information Society Technologies (IST) [12]. Searches were also performed using Internet search engines.

The following relevant peer-reviewed journals and databases were searched: Journal of Telemedicine and Telecare, Telemedicine and e-Health Journal, IEEE, Medline and Inspec to identify published information about the design of the remote patient monitoring studies.

III. Results

Thirteen current or recently ended RPM projects and services in the UK were identified. Eight projects monitored Chronic Obstructive Pulmonary Disease (COPD), four Chronic Heart Failure (CHF), one diabetes, one various acute unstable conditions such as heart conditions, blood pressure and pulse, and one monitored patients on oxygen

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therapy and nebuliser trials. Five projects monitored more than one disease. Five mainly aimed to improve the management and outcomes of chronic diseases with acute episodes, three aimed at enabling patients to return home early after a hospital admission, and two sought to reduce hospital admissions through early intervention in the case of deterioration. Again, there was overlap between some of the objectives. Two projects were primarily aimed at assessing the benefits or feasibility of remote patient monitoring.

Equipment from four different vendors was being used: Tunstall, American Medical Devices (AMD), Docobo and Viterion. We found that the choice of equipment heavily influences the organisation of the monitoring, since the technology determines much of the data flow between the different parties.

Two types of system emerged: one without (type 1), and one with (type 2) a 24-hour telemonitoring centre, as can be seen in figures 1 and 2.

In the type 1 system, the patient is equipped with a telemonitor, which records their physiological measurements, displays some of them to the patient (e.g. blood pressure), and forwards them to a data server. At the data server, the data is analysed according to parameters that have been set by a clinician, and processed so it can be displayed graphically and/or textually. If a measurement falls above or beneath the pre-defined threshold, an alarm is raised. Clinicians usually view their patients' data via the Internet. This type of system is characterized by a minimum of integration into the healthcare service, and is typically a commercial service.

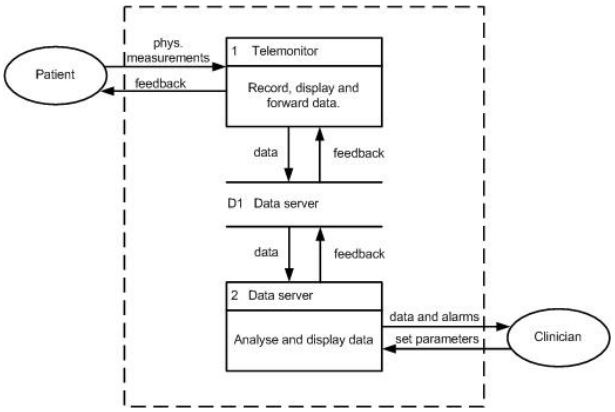

FIGURE 1: CURRENT DESIGN OF RPM IN THE UK – TYPE I

Type II monitoring (figure 2) is characterized by the addition of a 24-hour telemonitoring centre, which means that alarms can be responded to around the clock. This makes the monitoring suitable for acute conditions that need constant attention. It also gives patients access to medical and technical assistance out of hours. According to the pre-set parameters, data is divided into routine, i.e. non-urgent and urgent. Routine data is simply stored on the server for later review by the patient's clinician, while urgent data is forwarded and responded to by the 24-hour telemonitoring centre. Staff at the centre are typically nurses working for the equipment manufacturer. They will usually phone the patient and then determine the best course of action.

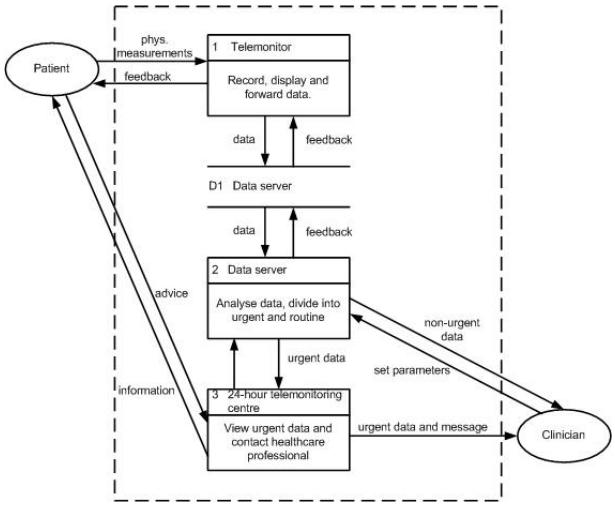

FIGURE 2: CURRENT DESIGN OF RPM IN THE UK – TYPE II

We have observed that the systems have been established in isolation from normal services, and design contains few, if any, links to primary or community care, nor is the clinical data integrated at any level.

Based on the shortcomings of the current set-up of RPM projects, we have developed a design for a clinically and organizationally more integrated monitoring system (figure 3). We have chosen to base it in primary care. This also matches current government efforts to shift services into primary care [13]. Key to the design is the involvement of other healthcare services such as 24-hour emergency cover which might be provided by the Accident & Emergency (A&E) department of the nearest hospital, a specialist centre, which provides hospital services in the community, the out-of-hours GP service, or Social Services for non-medical problems. We would advocate a team-based approach with information-sharing across different healthcare sectors for continuity of care. The present system is very fragmented, which can lead to the loss and duplication of information.

Integration with social services will often be necessary as a significant number of elderly people are also frail and require daily support, or suffer from dementia. Social Services also tend to be responsible for environmental monitoring and social alarms, and ideally these should be integrated with medical monitoring, as similar patient groups are involved. The patient's carer/s should also be utilised where available.

A 24-hour telemonitoring response centre is essential if the monitoring is to make a real difference to patients' health, especially with acute conditions. Routine, i.e. non-urgent, data is forwarded directly to the clinical team which primarily looks after the patient. In the UK, this is the GP along with the nurses at the heath centre the patient is registered with. This ensures that the monitoring is an

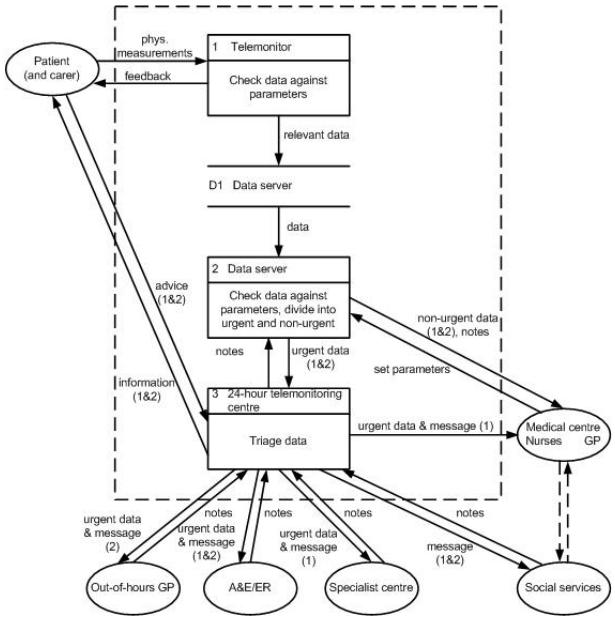

FIGURE 3: OPTIMUM DESIGN OF RPM IN THE UK
(1) During office hours; (2) Out of hours

integral part of the patient's long-term care, which is not possible in a hospital-based system. At the 24-hour telemonitoring centre, which is staffed with experienced nurses and perhaps other specialised healthcare professionals, urgent data is triaged, and forwarded to the most appropriate services for immediate action. When the patient has been responded to, the service provider inputs information about the patient's status into the system, which can then be accessed by the GP, who usually manages the patient. This ensures that there is no "gap" of information between the different healthcare services, as is otherwise the case. Since the information is in electronic format, it is also available immediately and to several parties simultaneously.

The level of support provided needs to be tailored to the needs and abilities of each patient. A patient who is mentally alert and interested in self-managing their disease, should be encouraged to be involved, since it is likely to benefit the development of their condition. It is also important that the telemonitor supports monitoring of all the common physiological parameters, so they can be added and removed as needs change.

IV. DISCUSSION

Our research aims to contribute to the big question of how to make RPM part of mainstream healthcare. We propose an RPM system that is clinically and organizationally embedded in the healthcare system, by sharing information with all the services involved in looking after the patient. It is also important to involve the patients themselves in the management of their condition.

It has been argued that as patients' dependency increases from simple telecare (e.g. assistive technology) to vital signs monitoring, the need for a close integration with the wider healthcare system grows accordingly [6]. This also applies to the different levels of RPM. For the periodic monitoring of a chronic disease, integration is not as critical (although recommended) as it is for continuous monitoring of a patient with acute illness. Acute monitoring relies on immediate intervention, which requires closer collaboration of healthcare staff from different organisations.

Our integrated solution enables the monitoring of patients with the majority of long-term (chronic) and acute conditions.

The present systems carry out very little data analysis, and most is forwarded for human analysis. If projects are to grow, this is not feasible. Our solution therefore proposes initial data analysis by the telemonitor at the patient's side, which will enable the discarding of irrelevant information and the forwarding of relevant data to the server. What information should be forwarded needs to be determined by the team who is responsible for the patient. Further analysis is then carried out at the data server, and a distinction is made between urgent and routine data. Only urgent data will be assessed by a healthcare professional immediately. Routine data can be reviewed as part of the patient's long-term disease management. This eliminates unnecessary work for healthcare professionals.

Five of the thirteen projects we identified focus only on a single disease. This is not ideal, as a monitoring service that supports a wide variety of conditions can serve the whole patient community who requires it. Therefore, the equipment should be able to measure a wide variety of parameters.

The problems with integration are not solely a result of the telemonitoring not being integrated into the healthcare service, but rather the healthcare service itself being fragmented. Currently, there is very little collaboration between primary care, secondary care and social services, although the population these sectors serve is similar. This problem may have become apparent through the failure of RPM to be utilized on a mainstream basis, but it cannot be solved with technology. Partnerships need to be formed across these sectors, which can be aided by technology such as shared electronic clinical data.

V. CONCLUSION

We have identified thirteen current or recently ended RPM projects in the UK. A clear lack of integration into mainstream healthcare could be observed, which is a key factor in the slow clinical uptake of RPM. To overcome the low level of integration, we proposed the design of an integrated RPM system. It is based in primary care, and involves different healthcare services such as a hospital's Accident & Emergency department, the out-of-hours GP service, a specialist centre and social care.

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