Personalised Ambient Monitoring (PAM) of the mentally ill

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Abstract — **One in ten of the (UK) population will suffer a disabling mental disorder at some stage in their life. Bipolar disorder is one such illness and is characterized by periods of depression or manic activity interspersed with stretches of normality. Some patients are able to manage this condition via their self-awareness that enables them to detect the onset of debilitating episodes and so take effective action. Such self management can be achieved through a paper-based process, although more recently PDAs have been used with success. This presentation will introduce the Personalised Ambient Monitoring (PAM) concept that aims to augment such processes by automatically providing and merging environmental details and information relating to personal activity. Essentially the PAM project is investigating what may be loosely referred to as 'electronic' monitoring to automatically record 'activity signatures' and subsequently use this data to issue alerts. The types of data that we are considering using includes: location and activity (e.g. via GPS and accelerometers); and environment (e.g. temperature and light levels). Other types of sensor under consideration are passive IR sensors (within the home); and sound processing to log the audio 'environment'. The use of such monitoring will be agreed between the patient and their health care team and it is anticipated that different patients will be comfortable with different sensor packages, thus personalizing the monitoring. Although such tele-monitoring is now generally common, its use in the treatment of the mentally ill is still in its infancy. This paper will consider the specific problems faced in applying it to this community along with the aims of this project. In addition, the use of modelling to predict the effects of the possible problems of sparse data that is expected, and to predict the effect on the overall patient pathway will be considered.**

Keywords — **activity monitoring, actimetry, tele-monitoring, psychiatric illness, bipolar disorder.**

I. INTRODUCTION

91 million working days are lost each year due to mental health problems and the cost to the United Kingdom is £32 billion in lost productivity and treatment costs. In addition to this financial burden to the country as a whole there are of course the personal costs to individuals, their family and friends [1]. Recent efforts announced by the UK Government "will help people with long-term conditions such as cancer, or mental health problems, to stay independent and take control of their illness" by providing information with medication. PAM (Personalised Ambient Monitoring) will take this even further by allowing patients to select off-the-shelf technology that will monitor their "activity signatures"; measurements of behavioural patterns which indicate people's mental health state. PAM will use a set of multiple discreet sensors, both body-worn and in the person's home, coupled to a computer system programmed to detect changes in activity signatures and so when appropriate issue automatic alerts to the patient, their family, or their doctor, thus providing the capability to avert debilitating episodes.

PAM will be working in particular with Bipolar Disorder (BD) which is a mental disorder that affects approximately 0.4–1.6% of the population [2]. BD is characterized by recurring episodes of mania and depression, which can vary in recurrence from a few weeks to many months. Symptoms of mania include elevated mood, increased activity, pressure of thoughts and speech and decreased need for sleep; whereas, symptoms of depression include decreased activity, sleep disorders and depressed mood. [3]. The current standard for pharmacological treatment of BD is lithium, which can be taken both in the acute stages of the disorder as well as a prophylactic. However, around 20-40% of patients do not respond to lithium [4] and around 75% of patients report side effects, which can be numerous and severe [5]. Other medications, such as anti-psychotics and anti-depressants are a common alternative to lithium [5]. Therapeutic treatments for BD use a number of approaches, such as cognitive behaviour therapy, social rhythm therapy and family therapy [5]. Identification and management of the early warning signs of an oncoming episode are paramount in most therapeutic treatments of BD, and it has been shown [6] that patients who are able to identify and act on the early warning signs are better able to manage their condition and maintain a more stable health condition as a result.

This pilot study will investigate the feasibility of reducing the incidence of debilitating episodes of BD. This will be achieved by longitudinal monitoring that will permit

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testing of the hypothesis that it is able to provide early detection of deteriorating health and so prevent avoidable hospital admissions.

II. Methodology

The overall aims of the PAM project are to address two main questions:

- Is it possible to obtain, in an automatic, ambient and unobtrusive manner, 'activity signatures' from the mentally ill (BD) that provide information about the trajectory of their health status?
- If this is so; can this information be used to assist their healthcare?

Paper-and-pen-based reporting tools have been used to perform long-term Bipolar Disorder patient-monitoring [7]. Recently, electronic data collection tools have been deployed on handheld devices and validated against paper-and-pen-based data collection [8]. Handheld reporting tools were shown to provide as accurate results as paper-based collection in healthcare and clinical research. However, handheld data collection is superior because it automates the monitoring process. One of the aims of the PAM project is to take the next step by fusing self-reported data with relevant sensor data collected and processed on a regular basis in an ambient, unobtrusive and ethical manner that is acceptable to the individual being monitored. A further aim of the project is to evaluate the impact on the health service: including cost, resource, and effectiveness.

The concept of the remote monitoring of patients has already been tested in many other areas of e-health and telemedicine such as emergency-response [9], assisted-living and geriatric rehabilitation [10], respiratory and chronic heart failure [11], diabetes and obesity [12] and Sudden Infant Death Syndrome (SIDS) [13]. The information we propose to acquire and use includes data from both body-worn sensors (and ones incorporated into clothing) plus others in the home to detect activity and movement together with other personal sensors to detect proximity to other environments or people (e.g. via Bluetooth connections). We will be building upon existing work in this area from centres and projects such as the Bath Institute of Medical Engineering (BIME) [14], Ubiquitous Computing for Healthcare in the Community (UbiCare) based at Imperial College [15], Extending QUAlity of Life of older and disabled people project (EQUAL) [16] and Strategic Promotion of Aging Research Capacity (SPARC) [17].

We do not propose to continuously collect data at some central point and so do not require a "consistent" Quality of Service (QoS) from the communications infrastructure. Rather we anticipate the data obtained is likely at times to be sparse, incomplete, and vary from individual to individual (due to their preferences about what is acceptable to monitor). Only after local processing at the sensor level will processed data eventually be fed to a central computer for analysis, annotation and archiving. The output of this analysis will be used to trigger alerts (of varying severity) to the patient themselves and/or to their care network. In addition to this conventional model we also intend to investigate the potential of local processing at the sensor (or perhaps multiple sensor level), not only for data compression, but in order to trigger more immediate alerts prior to data transmission to a central base, or indeed if transmission links are inoperative. Fig. 1 depicts the proposed system infrastructure for the PAM system. More details about the infrastructure can be found in [18].

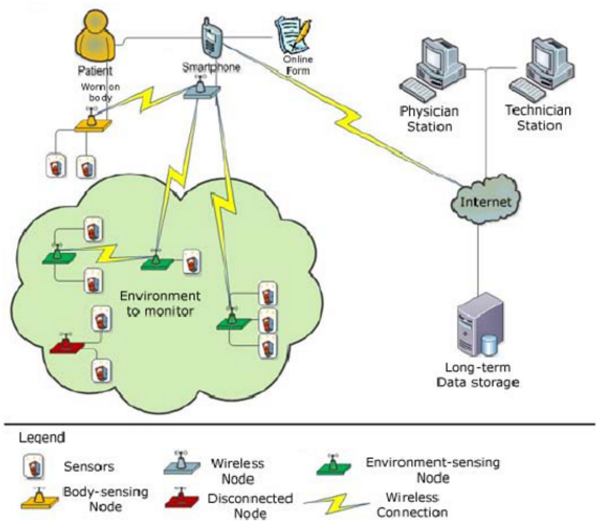

Fig. 1 An overview of the proposed system infrastructure

PAM incorporates two distinct themes: (i) the provision of embedded real-time algorithms to detect behaviour patterns, and (ii) the ability to provide a self-configuring network with the minimum of infrastructure. Both themes are underpinned by Operational Research (OR) that models the identification of modalities, the positioning of sensors, the fusion of this data, and the extraction of important patient behaviours. PAM specifically will address the following four major areas of research:

A. Ambient Monitoring: This is a well-established telecare theme seen for example within initiatives such as EQUAL [16] and SPARC [17], and on-going initiatives such as Smart and Aware Pervasive Healthcare Environment (SAPHE) [19] and Ubiquitous monitoring environment for wearable and implantable sensors (ubiMON) [20]. BIME [14] has used telecare for people with dementia, and the Scottish Mobilising Advanced Technologies for Care at Home (MATCH) project [21] is focusing on monitoring and support of aging people with a strong emphasis on a wide range of modalities and the use of policies for coordination. The PAM system will perform long-term monitoring of patients living at home, using ambient sensors discreetly placed in their environment and worn or carried by them. The devices will passively record data, detect subtle changes to the patients' activity signatures and relate these changes to specific aspects of their conditions. The devices will be unobtrusive to the patients; that is, whilst the sensors will not be hidden from the patients, they will also not be unpleasantly noticeable in the environment. By minimising the obtrusiveness of the technology we hope to sample activity signatures with a high-degree of accuracy. As is pointed out in [22], sensors can be installed in a subject's home and then forgotten about by the subject in a few days. Ambient monitoring requires little interaction with the subjects and the system can auto-configure [19]. In recognition of ethical and privacy issues, and the recommendations from [23], the patients will be able to access data collected about them through a form of self-investigation and learn about aspects of their lives that impact their mental, social and physical health. In addition warnings will be sent to patients' health-care providers as detailed in patient care contracts. To support multi-sensor data collection and reporting, the devices will form an ad-hoc communication network. Roaming gateway software will be installed on the patients' mobile phones to transfer operating procedures to devices and coordinate sensor and network data collection. Middleware installed on the devices will facilitate device registration, task assignment and secure data transfer. Key to our approach will be the support of data processing close to the sensors. Such processing can be changed at run-time to provide flexibility and adaptability.

B. Behavioural analysis: Rather than record and analyze all the data at a central point we will employ signal processing techniques to extract meaningful information from the data, to provide real-time embedded processing capabilities. Algorithms that learn from normative data and that can deal with missing data-points will be designed. Models of normal activity signatures can be derived through a combination of computational intelligence based techniques such as multi-dimensional clustering followed by probabilistic modelling. As a generative model of normality will be devised using multi-dimensional inputs, robustness to missing data points can be built into the system. The advantages of computational intelligence based methods (such as artificial neural networks) is that once trained they provide a single layer model which can be readily and speedily embedded into such a distributed network. Appropriate algorithms will be then used to pare down the data received so that details sent are directly relevant to the patient's mental health state.

C. Sensors: The sensors will be chosen to estimate a person's 'activity signature'. This may include factors such as geographical location and physical activity (via, for example, GPS and accelerometers) alongside 'social' activity via monitoring of place and contact (via, for example, Bluetooth connections, mobile phone usage and audio 'environment'). Information in the home environment will draw from the existing extensive research in this area aimed primarily at the care of the frail and elderly. OR modelling of the information content of this data will inform whether it possesses redundancy (as is likely) and if so what sensors may be omitted with minimal loss of significant information. Sensors may be wired or wireless depending upon type and where the data produced is processed and stored. Ultimately it is probable that standard mobile phone networks will be used for data transfer whilst the use of mobile phones for data processing and storage, with transfer from sensors via Bluetooth, will also be explored.

D. Operational Research: OR is an analytical discipline that involves the use of mathematical models to assist decision-making in a vast range of settings: industry, business, health and defence. Within PAM, OR modelling will provide a sound basis for the choice of modalities, sensors and subsequent processing. Through the use of computer simulation, the uncertainty around the actual performance and reliability of the system of sensors will be explored and the potential usefulness of PAM can be evaluated in a range of different scenarios. Since a full-scale clinical trial is not practicable in this project, simulation will provide information on the clinical value of the information that PAM could deliver under varying circumstances, such as the failure (or deliberate removal) of one or more of the sensors, or a patient's unwillingness to have sensors in specific locations, or the limited availability of various types of data.

At the heart of the simulation model is a "natural history" model for BD, based on the clinical literature, reflecting the way in which an individual gradually moves from a healthy state into illness. The inputs for this model include clinical, social, demographic and environmental factors, as well as the characteristics of a given configuration of PAM sensors in terms of technical performance, acceptability to the patient, and reliability. These features will be described by probability distributions, to capture uncertainty and variability in the parameters. This model will produce as output an "activity signature" which will be automatically checked against the baseline signature for that individual, to see if true changes in the patient's mental health state could be detected. Sufficient iterations of the model will be performed to enable statistically valid inferences to be drawn about the accuracy of the PAM output for that individual. This process can be repeated many times for different combinations of inputs, to allow overall conclusions to be drawn for a range of different patients and scenarios.

III. Conclusions

Through the PAM philosophy it may be possible, through behavioural signatures, to identify trends in behaviour. Variations from these trends could be used to trigger notifications to the individual themselves, to their carers and/or to the health professionals (based on an agreement entered into by the patients themselves). Exploring this concept will not only allow us to investigate the benefits to the patients themselves, but also permit exploration of how the acquisition and use of such signatures can be integrated into healthcare plans. This will include the benefits through more timely interventions (and any unexpected problems) that such technology will provide to healthcare professionals in performing their duty of care. We envisage that the same technology may be applicable to other patient groups with very little changes required which is the reason why an intentionally very flexible system has been chosen.

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