

# M-Psychiatry: Sensor Networks for Psychiatric Health Monitoring

Jesse Blum, Prof. Evan Magill  
Department of Computing Science and Mathematics  
University of Stirling  
Stirling, UK  
{jmb, ehm}@cs.stir.ac.uk

**Abstract**—Long-term monitoring of patients with affective disorders has been shown to reduce certain types of episodes and improve social functioning. However, most of the research to date has been based on patient-reported data, which exhibits certain deficiencies including failure to detect depressive aspects of the illness. Questions have also been raised about the accuracy and completeness of patient-reported data. Enhancing patient-reported data with environmental and physiological recordings could improve the accuracy and completeness that current solutions are missing. This paper describes procedures for the fusion of patient-reported data with remotely-sensed patient-centred data collected using small wireless devices placed on patients and in their homes.

## I. INTRODUCTION

Bipolar disorder is a chronic mental illness that has a significant impact on the individual and society. The disease has detrimental effects on patient quality of life [1] [2], and a high cost for social and health care<sup>1</sup>.

Long-term self-monitoring of patients with the illness has been shown to benefit patients, care providers, and researchers [3], but is not a panacea. Patients have been taught to self-monitor using paper-based forms, and recently, computerised versions of the forms for handheld devices have been developed and validated against traditional paper-based versions [4]. Unfortunately, as we will discuss in the next section, the efficacy of self-monitoring systems has inherent issues. There is therefore, considerable value in enhancing self-monitoring systems with ambient-monitoring solutions to detect depressive prodromes early enough to intervene, reduce the effort required by patients and care providers to monitor effectively through ambient monitoring, and monitor physiological and contextual details.

The Personalised Ambient Monitoring (PAM) project is investigating the feasibility of reducing the incidence of debilitating episodes through personalised ambient monitoring of patients in their homes. We are attempting to collect patient activity signatures in an ambient and unobtrusive manner. We plan to deploy miniature physiological and environmental sensors, worn by patients, and placed in their homes to collect the data. This is in line with the vision of mobile healthcare

<sup>1</sup>In 2002, the annual cost of managing the illness by the UK National Health Service was estimated to be £199 million, of which £70 million was spent on hospital admissions [6].

(M-Health) given in [5]. From this perspective, PAM can be seen as an M-Psychiatry<sup>2</sup> project.

An M-Psychiatry solution could provide patients and clinicians with greater insights into the patterns of mental illnesses. Patients could be given control over the monitoring system via their mobile phones, or other handheld devices. These devices could be used as gateways to relay important information and alerts from the sensors to the patients and their care providers, and to program and monitor the network. Sensor readings could be fused with self-reported data from electronic forms, and augment existing systems. The ambient collection of signature data could be supported by a wireless sensor network (WSN) infrastructure, and a programming architecture that allows the development of novel, context-aware, adaptive sensor configurations.

This paper examines the technological design issues involved in an M-Psychiatry solution to this type of data collection and transmission problem. The rest of this paper is outlined as follows. The next section provides additional details regarding recent technological developments in treating bipolar disorder, and discusses the value of including wireless sensor monitoring intervention. Section 3 reviews the state of the art in health sensor networks. Section 4 describes a potential architecture for fusing body sensor data, environmental data and patient-reported data. Section 5 considers how the sensing architecture can be programmed to recognise particular aspects of mental illness. Section 6 concludes the paper.

## II. MOTIVATION AND BACKGROUND

Bipolar disorder is a multi-faceted disease with a long-term chronic nature. Symptoms of the disease vary amongst the disease sufferers, and the symptoms change over a patient's lifetime. Treatment plans, therefore, are difficult to establish. To develop effective treatment plans, care providers have become interested in tracking the patterns leading to episodes (prodromes), and the frequency and duration of episodes. Long-term monitoring of patients with the illness has been shown to benefit patients, care providers, and researchers [3]. Paper-and-pen-based self-rating instruments have been

<sup>2</sup>We define M-Psychiatry as "Mobile computing, sensors, and communications technologies for psychiatric health-care"

developed to comprehensively describe the patterns of the illness in a cost-effective and easy-to-use manner. In many cases, patients have been taught to self-monitor using the forms, and computerised versions of the forms have been developed for use on handheld devices.

The changeover from paper-and-pen-based reporting to handheld-based reporting has resulted in benefits to patients and care providers. Handheld data collection was shown in [7] to provide as accurate results as paper-based collection in healthcare and clinical research. In addition, it was reported that handheld collection was preferable to paper for a number of reasons. These included user preference, responsiveness, document security and privacy, and time, labour and cost savings. [8] reports that their electronic version of a paper-based monitoring form for bipolar disorder monitoring had a cost savings of 90% when compared with the equivalent paper-based solution. They also report increased patient motivation to complete daily monitoring activities. Clinician data entry reduction, prevention of data entry errors, reduction of missing information, and standardised data collection, are benefits of self-reporting with the electronic tool reported in [9]. The study also demonstrated validity between their tool and a paper-based depression rating scale. In addition, [4] reports that no significant demographic differences were found by comparing patients using paper-based forms and patients using an electronic recording system.

Self-monitoring systems, whether paper-based or electronic, have downsides. Self-monitoring has been shown to reduce manic episodes, improve social functioning and improve employment [10]. However, the reduction of depressive relapses has not been established, and it is unclear whether there has been any impact on quality of life or cognitive functioning. In addition, patient factors have been shown to lead to a reduction in the efficacy of the system over time. For instance, some patients report becoming complacent about the therapy [11]. Patients have also reported that the effort and vigilance required to self-monitor makes them feel different from others. A further detractor of self-monitoring is its inherent reliance upon the accuracy and honesty of the patients' awareness of their illness. Furthermore self-monitoring lacks the ability of reporting physiological and patient context details that could be very useful in making treatment decisions.

Future systems should concentrate on augmenting the results of self-monitoring to reduce depressive episodes, reduce the effort required by patients and care providers to monitor effectively, and add physiological and contextual details to the reports. Sensor networks have emerged over the past few years as a potential tool that could be used to augment self-reporting tools with information required to help recognise and minimise manic and depressive episodes. Sensor networks are collections of small devices that monitor physical events and report about them. Often sensor networks use wireless communications to regulate their activities and convey their results. The sensing devices can be placed in the environment or be worn by patients. Sensor networks have been proposed for medical monitoring in [12-15]. They show considerable

promise regarding the goals of dynamic completion of physiological and environmental information, and could potentially benefit early prodrome detection and episode recognition. In order to achieve these goals, the devices, services they offer, and data they provide need to be configurable, reliable, private and secure. The data from sensor networks could be fused with self-reported data to describe the trajectory of patient mental health.

### III. RELATED WORK

Handheld devices have been proposed for self-monitoring of bipolar disorder in [8] and [9]. Correlations between handheld solutions and traditional paper-based systems were shown in [7]. However, these systems suffer from reliance on the patient to record the data, and have not been shown to monitor certain aspects of the disease with adequate fidelity. Psychiatric sensor systems would relieve patients of the burden of constant monitoring, and possibly detect prodromes earlier and with a greater degree of accuracy.

Wireless sensor networks have been proposed for general medical care in a number of research projects. The Codeblue software framework [12] [21] provides a number of protocols to build sensor networks for a variety of medical settings. However, its focus tends to be on emergency response and robust communications. The architecture they describe may not be appropriate for long-term in-home monitoring of the mentally ill that can result in sparse datasets. ALARM-NET is an architecture for monitoring environmental and physiological data of individuals in assisted-living environments and in their homes using wireless sensor nodes, gateways, PDAs, and back-end systems for data storage [13]. The project team have developed a program to use circadian activity rhythms to aid context-aware power management and privacy policies. ALARM-NET uses a query management middleware to enable system interaction and data collection. MobiCare is a body sensor network (BSN) employing a programmable, reconfigurable service model for patient care. Experimental results have been reported in [14] about a wireless testbed involving Bluetooth and GPRS/UMTS communications infrastructure. MobiCare healthcare service descriptions are based on their application protocol built on top of HTTP. The UbiMon BSN architecture has been designed to interconnect wearable and implantable sensors using ad-hoc networking [15]. Activity and context recognition have been a large focus of the project. To our knowledge, these systems have not been applied to mental healthcare and do not integrate self-monitoring reports. In addition these systems do not attempt to deal with differences resulting from heterogeneous service level contracts between patient and care provider.

Pervasive computing solutions have begun to be proposed for mental illness monitoring and prevention. In [22], the researchers recorded video and audio in the dementia unit of a nursing home, then processed the recording to automatically identify interactions and behaviours of the mentally ill. The use of video and audio, however, is often seen as overly invasive,

and furthermore it may not be feasible to set up multiple cameras and microphones in home environments. Wireless sensors have also begun to be used in pervasive mental healthcare applications. The LiveNet wearable platform [23] has been designed specifically to use mobile physiological sensors to perform long-term ambulatory health monitoring. It has been used in a study to monitor the effects of undergoing electroconvulsive therapy for depression. LiveNet demonstrates the possibility of mental illness monitoring, but is limited to on-body sensing, does not integrate self-monitoring information, has not been applied to bipolar disorder, and has not been deployed in a home environment.

#### IV. INFRASTRUCTURE AND MIDDLEWARE

The following sensor network infrastructure is proposed for ambient mental health data collection and reporting meaningful information to patients and care providers. This system is based on wireless communication. Wireless sensor networks (WSN) have various dimensions and no single solution has been provided to cover every aspect. Some of these dimensions have been described in [20].

##### A. Characteristics of the PAM WSN

We envision using a collection of sensing nodes to collect data from different types of sensors, identify behavioural signatures in realtime, and transfer wirelessly the signature information. Sensing nodes can communicate with each other and a mobile gateway that relays data between the network of sensors and the Internet. Sensing nodes are composed of three types of components: communications transceivers, sensors, and ultra small computing boards featuring power source, limited memory, and I/O connections.

Our vision addresses a number of characteristics including: the sensing platform's form factor and resource constraints, mobility, connectivity and coverage requirements, communication modality and network topology, deployment methodology and system lifetime, service quality constraints.

The sensors used will vary from patient to patient and the software architecture will allow the registration and substitution of a wide variety of devices. Whilst the sensors will be heterogeneous, we expect that the nodes will have homogeneous characteristics including processors, memory and transceivers. Each node will have a matchbox size form factor, have a radio-based communication modality, and have enough computing resources to support the behaviour processing and middleware. The deployment of the nodes will be handled manually by technicians in accordance to service level contracts agreed to by patients and care providers. The types, numbers and positions of the nodes may change over time. The lifetime of the system is expected to be longterm.

The network will adapt to partial, occasional and passive node mobility. Some of the sensing nodes will be deployed in the patients' living environments and some will be worn or carried. Sparse coverage of the areas of interest may result in node isolation and limit communication to intermittent levels as the mobile gateway passes within range of isolated nodes.

The nodes may communicate with each other and with the mobile gateway using an ad-hoc network infrastructure.

The network is expected to deliver sensitive data about the health of the patient. The patients' privacy and the security of the data are important service constraints influencing software architectural decisions. Another factor is that the monitoring of the patients must be under their own control, and they must have the ability to turn the monitoring off when they want to.

##### B. The Personal Ambient Monitoring Infrastructure

The Personal Ambient Monitoring Infrastructure (PAMI) displayed in figure 1 fuses body sensor data, environmental data and patient-reported data. The results are recorded securely in a long-term data store and can be examined by health care professionals. Technicians will also be able to access the network for maintenance purposes. PAMI is composed of five key technologies: the body sensing platform, wireless environmental sensors deployed in the home and other patient monitoring environments, the network gateway, an ad hoc communications network, and the query stations.

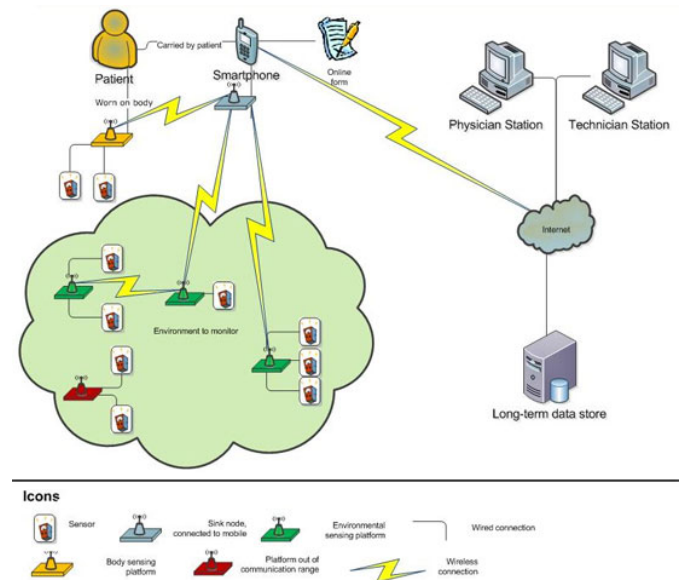


Fig. 1. The PAMI infrastructure

##### C. Body Sensing

Body sensor networks (BSN) have emerged as a technology to incorporate sensors located within the personal area of an individual. The sensors can be used to track physiological data such as heart rate and blood oxygen levels, as well as contextual information such as light levels and user motion tracked through accelerometers. Sensing nodes can be worn by patients and used to track changes to physiology. BSN technology is still experimental and active research topics include power-management related issues, signal processing, security, data-fusion and decision support.

#### D. Environmental Sensing

Sensors in the patient environment can be used to track conditions such as light levels and temperature, and be used to track patient behaviour in the environment. This can be accomplished by monitoring how the patient moves through their homes, and the ways they perform their activities of daily living (ADL). Multiple sensing nodes can be placed in the environment and can use different sensors, for different tracking tasks.

#### E. The Network Gateway

Sensing nodes need somewhere to communicate data to and also need to receive updates to their operating procedures. In PAMI, this information gets routed via a mobile gateway to the network. Monitoring instructions and application rules are routed from physician and technician stations to the gateway. The gateway, deployed on the patient's mobile phone, includes software and a sink node radio that allows a standard smartphone to communicate with the sensing nodes. All communication between the gateway and the Internet must be secure and private.

#### F. Query Stations

Clinicians need to monitor their patients, and technicians need to make sure that the monitoring equipment and network is operational. In order to meet these needs, applications will be developed to alter monitoring patterns and query historical patient data, as well as report the current state of the system.

#### G. Middleware Protocols

To perform monitoring, maintenance, and data fusion tasks, we will need to develop sensor network protocols. These protocols might be implemented on top of existing WSN middleware such as COUGAR [24], SINA [25], TinyLIME [26], or MiLAN [27], or employ middleware solutions involving OSGi [28], EQUATOR's EQUIP platform [29], or a custom made solution.

We are planning to develop two new protocols to support the system. The Task Assignment and Data Advertisement Protocol (TADAP) will support programming configurations of nodes to perform a variety of monitoring services and advertise their results. The Sensor Management Protocol (SMP) will regulate the data aggregation, time synchronisation, and secure data transmission. SMP will also report the state of the sensors and control the system's on/off state. TADAP and SMP were initially envisioned in [19], and we plan to develop them as a basis for M-Psychiatry solutions.

### V. PRODROME & EPISODE RECOGNITION

It is possible for clinicians and patients to identify early symptoms of depressive or manic episodes. Monitoring these early symptoms, known as prodromes, and intervening upon detection, has been shown to reduce the impact of the disease [17]. The question remains whether an electronic monitoring system can augment the results and provide a better level of care.

Activity recognition by wearable and environmental sensors has been a popular subject of research and has shown promising results. As Tãm Huÿnh et al. point out, most of the research has focused on identifying lower-level activities such as walking and sitting, but it is possible to recognise higher-level activities such as cleaning the house [18]. Prodrome recognition requires the recognition of both levels of activities. For instance, [17] reports that the prodromes for mania and depression include sleep disturbance, mood changes, psychotic symptoms, psychomotor symptoms, suicidal ideas and intent, appetite changes and anxiety levels, as well as other indicators. High-level and low-level activity monitoring is required to recognise these disturbances.

In order for PAMI to recognise a disturbance, it will be programmed with descriptions of behaviours to monitor, and irregularities to identify. The descriptions must be written in a language that is understandable by clinicians, and translated into sensor configurations and service requirements. Since some patients may object to the use of certain sensors, and sensors will not be universally present, the descriptions must support alternative sensor configurations. For instance, a hypothetical approach to monitoring for sleep disturbances could involve the use of only motion sensors and actigraphy, whilst another might also include bed sensors and heart rate monitoring. In addition, the high-level concept of sleep would have to be described in terms of particular patterns of device activation. Observation metrics need to be described in order to identify irregularities. To create these descriptions we will translate well known psychiatric rating scales into service descriptions, using the task assignment protocol.

Service descriptions will be supported by TADAP for task assignment. TADAP will support mechanisms to inject behaviour-recognition algorithms into the sensors, and translate service descriptions into configurations of sensors attempting to monitor for phenomena and triggers (fig 2). The protocol will also control how the configurations of sensors advertise their observations.



Fig. 2. Sensor configurations monitoring different phenomena

## VI. CONCLUSIONS

The ability to apply M-Psychiatry to perform long-term monitoring of patients with affective disorders is technologically feasible. Doing so could improve the results of current systems that rely exclusively on self-reported data. We propose flexible protocols that support alternative service level agreements and monitoring equipment to provide individualised intervention appropriate to different patients. The infrastructure employs small on-body and environmental sensors, and a mobile gateway. Future work involves developing the TADAP and SMP protocols, the sensing algorithms and developing prototypes to demonstrate the system.

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## REFERENCES

- [1] L. Yathama, et al., "Quality of life in patients with bipolar I depression: data from 920 patients," *Bipolar Disorders*, vol. 6, pp. 379-385, 2004.
- [2] E. Michalak, L. Yatham, and R. Lam, "Quality of Life in Bipolar Disorder: A Review of the Literature," *Focus*, vol. 5 pp. 117-134, Winter 2007.
- [3] C. Baldassano, "Assessment tools for screening and monitoring bipolar disorder," *Bipolar Disorders*, vol. 7, supp. 1, pp. 8-15, April 2005.
- [4] M. Bauer, et al. "Does The Use Of An Automated Tool For Self-Reporting Mood By Patients With Bipolar Disorder Bias The Collected Data?" *Medscape Journal of Medicine*, vol. 7, issue 3, 2005.
- [5] R. Istepanian, E. Jovanov, and Y. T. Zhang, "Guest Editorial Introduction to the Special Section on M-Health: Beyond Seamless Mobility and Global Wireless Health-Care Connectivity," *IEEE Transactions on Information Technology in Biomedicine*, vol. 8, no. 4, pp. 405-414, December 2004.
- [6] R. Das Gupta, and J. F. Guest, "Annual cost of bipolar disorder to UK society," *Br J Psychiatry*, vol. 180, pp. 227-233, 2002.
- [7] S. Lane, N. Heddle, E. Arnold, and I. Walker, "A review of randomized controlled trials comparing the effectiveness of hand held computers with paper methods for data collection," *BMC Medical Informatics and Decision Making*, vol. 6, May 2006.
- [8] L. O. Schrer, et al, "Life charts on a palmtop computer: first results of a feasibility study with an electronic diary for bipolar patients," *Bipolar Disorders*, vol. 4, suppl. 1, pp. 107-8, 2002.
- [9] M. Bauer, et al, "Using technology to improve longitudinal studies: self-reporting with ChronoRecord in bipolar disorder," *Bipolar Disorders*, vol. 6, no. 1, pp. 67-74, February 2004.
- [10] A. Perry, et al., "Randomised controlled trial of efficacy of teaching patients with bipolar disorder to identify early symptoms of relapse and obtain treatment," *BMJ.*, vol. 318, no. 7177, pp. 149-153, 16 January 1999.
- [11] R. Morriss, "The early warning symptom intervention for patients with bipolar affective disorder," *Advances in Psychiatric Treatment*, vol. 10, pp. 18-26, January 2004.
- [12] D. Malan, T. Fulford-Jones, M. Welsh, and S. Moulton, "CodeBlue: An adhoc sensor network infrastructure for emergency medical care," in *Proceeding of the International Workshop on Wearable and Implantable Body Sensor Networks*, 2004.
- [13] A. Wood, et al, "ALARM-NET: Wireless Sensor Networks for Assisted-Living and Residential Monitoring," *Technical Report CS-2006-11*, Department of Computer Science, University of Virginia, 2006.
- [14] R. Chakravorty, "MobiCare: A Programmable Service Architecture for Mobile Medical Care," in *Proceedings of UbiCare 2006: The First Workshop on Ubiquitous and Pervasive Healthcare*, March 2006.
- [15] K. Van Laerhoven, et al, "Medical Healthcare Monitoring with Wearable and Implantable Sensors," in *Proc. of the 3rd International Workshop on Ubiquitous Computing for Healthcare Applications*, 2004.
- [16] D. Roggen, B. Arnrich, and G. Trster, "Life Style Management Using Wearable Computer," In *4th International Workshop on Ubiquitous Computing for Pervasive Healthcare Applications (UbiHealth 2006)*, 2006.
- [17] A. Jackson, C. Cavanagh, and J. Scott, "A systematic review of manic and depressive prodromes," *Journal of Affective Disorders*, vol. 74, no. 3, pp. 209-217, May 2003.
- [18] T. Huynh, U. Blanke, and B. Schiele, "Scalable Recognition of Daily Activities with Wearable Sensors," *Lecture Notes in Computer Science*, vol. 4718, pp. 50-67, 2007.
- [19] I. F. Akyildiz, S. Weilian, Y. Sankarasubramaniam, and E. Cayirci, "A survey on sensor networks," *IEEE Communications Magazine*, vol. 40, issue 8, pp. 102-114, August 2002.
- [20] K. Römer, and F. Mattern, "The Design Space of Wireless Sensor Networks," *IEEE Wireless Communications*, vol. 11, issue 6, pp. 54-61, December 2004.
- [21] V. Shnayder, et al, "Sensor Networks for Medical Care," *Harvard University Technical Report TR-08-05*, April 2005.
- [22] S. Allin, et al, "Toward the Automatic Assessment of Behavioral Disturbances of Dementia," in *UbiHealth 2003: The 2nd International Workshop on Ubiquitous Computing for Pervasive Healthcare Applications*. Seattle, USA, 2003.
- [23] M. Sung, C. Marci, and A. Pentland, "Wearable feedback systems for rehabilitation," *Journal of NeuroEngineering and Rehabilitation*, vol. 2, 2005.
- [24] P. Bonnet, J. E. Gehrke, and P. Seshadri, "Towards sensor database systems," in *Proceedings of the Second International Conference on Mobile Data Management (MDM)*, vol. 1987 of *Lecture Notes in Computer Science*, pp. 3-14, 2001.
- [25] C. Shen, C. Srisathapornphat, and C. Jaikaeo, "Sensor Information Networking Architecture and Applications," *IEEE Personnel Communication Magazine*, vol. 8, issue 4, pp. 52-59, August 2001.
- [26] C. Curino, et al, "Mobile data collection in sensor networks: The TinyLime middleware," *Pervasive and Mobile Computing*, vol. 1, issue 4, pp. 446-469, December 2005.
- [27] W. B. Heinzelman, A. L. Murphy, H. S. Carvalho, and M. A. Perillo, "Middleware to Support Sensor Network Applications," *IEEE Network Magazine*, vol. 18, issue 1, pp. 6-14, January 2004.
- [28] "About the OSGi Service Platform," *OSGi Alliance Technical Whitepaper*, Revision 4.1, June 2007.
- [29] C. Greenhalgh, "EQUIP: a Software Platform for Distributed Interactive Systems," *Equator IRC Technical Report Equator-02-002*, Nottingham, University of Nottingham, 2002.