PERVASIVE HEALTHCARE:
CLINICAL DRIVE, TECHNOLOGICAL INNOVATIONS, AND
SOCIO-ECONOMIC BENEFITS

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ABSTRACT

In delivering high quality healthcare to large diverse population, we have to look at new forms of well-being and disease process monitoring with pervasive healthcare. This paper aims to explore the clinical drive, technological innovations, and socioeconomic benefits of such systems to human populations.

INTRODUCTION

Ever since the birth of modern medicine and the finding that audible sounds emanating from the chest are produced by the heart and lungs, diagnostic tools have continued to evolve to a point where they have revolutionised medical practice. In the fields of physics, engineering, biochemistry, and more recently genetics, advances in sensing technologies have resulted in the development of important diagnostic tools such as the stethoscope, blood glucose monitor, and recently genetic testing kits. Such advances have allowed not only the study and diagnosis of disease processes, but also a mode of monitoring their progress. Whilst prevention of disease is perhaps the most desirable form of treatment, early diagnosis, effective treatment, and accurate monitoring are the cornerstones of any effective healthcare delivery system.

In delivering healthcare to large diverse populations with “at risk” groups such as children, the elderly, and those with chronic disease, we have to look at new forms of well-being and disease process monitoring in the form of ubiquitous and pervasive healthcare systems. These offer a technological solution to the problems of looking after a vast number of people in a standardised manner. The development of wireless body sensor networks (BSN) offers a platform to establish such a health monitoring system, and represents the latest evolution of diagnostic tools. Human body monitoring with a network of wireless sensors may be achieved by either attaching these to the body surface or implanting them directly into tissues. BSN patient monitoring systems represent an important step towards pervasive healthcare delivery.

THE CLINICAL NEED FOR PATIENT MONITORING

The scale of the requirement for patient monitoring in healthcare systems can be easily illustrated using a few examples of common disease processes that currently place a large financial and physical burden on healthcare systems.

Cardiovascular diseases such as arrhythmias, are commonly encountered in clinical practice, in as many as 4% of the population over the age of 60, increasing with age to almost 9% in those over 80 [1]. Early symptoms include fatigue and palpitations with the condition diagnosed using electrocardiography (ECG) either during a symptomatic episode, or by prolonged monitoring using a 24-hour ECG holter. Once diagnosed, the patient is commenced on either treatment to control their heart rate, or on pharmacotherapy to prevent the long-term complications of this condition which include heart failure and stroke. A pervasive heart monitoring system would almost definitely result in this condition being diagnosed earlier, resulting therefore in an earlier initiation of treatment.

Diabetes mellitus is a well-known chronic progressive disease and can lead to the patient developing hypertension, peripheral vascular disease, coronary artery disease, and renal disease to name but a few. In the United States the prevalence of diabetes mellitus has increased dramatically over the past four decades, mainly due to the prevalence of obesity [2]. It is estimated that annually 24,000 cases of diabetes induced blindness are diagnosed, and 56,000 limbs are lost from peripheral vascular disease in the United States alone. The condition is diagnosed by measuring fasting blood glucose (which is abnormally raised) either during a routine clinical consultation, or as a result of complications of the condition. Once diagnosed, these patients require regular administration of insulin at several times during the day, with blood glucose “pinprick” testing used to closely monitor their blood sugar in between these injections. This need for repeated drawing of blood is invasive and therefore undesirable for many patients, yet there is at present no clear reliable alternative. In this group of patients a
Pervasive monitoring systems would most importantly be expected to monitor their diabetic control (blood glucose) as well as look out for evidence of other end-organ damage such as that mentioned above. BSN technology in this group would allow the networking of wireless implantable and attachable glucose sensors not only to monitor patient glucose levels but could also be used in “closed feedback loop” systems for drug (insulin) delivery.

DEVELOPING PERVERSIVE HEALTHCARE SYSTEMS

The concept of “ubiquitous” and “pervasive” human well-being monitoring with regards to physical, physiological, and biochemical parameters in any environment and without restriction of activity [3, 4] has only recently become a reality with the advances in sensor, miniaturised processors, and wireless data transmission technologies [5, 6]. Whilst external (attachable) sensors such as those for measuring vital signs, have continued to improve, it is the areas of implantable sensors and more recently biosensors that have generated much interest [7, 8]. Advances in key areas such as battery miniaturization, increased battery duration, reduced energy consumption, and power scavenging are essential areas of development for pervasive monitoring, particularly with regards to implantable sensors [9]. Micro Electro Mechanical System (MEMS) technology is another area which has offered the prospect of sophisticated, miniaturized, perpetual in vivo sensors [10].

Pervasive healthcare systems utilising large-scale BSN and wireless sensor network (WSN) technology will allow the clinician for the first time to be able to explore the prospect of not only monitoring patients more closely, but also in any environment. This may be in their own home, during their stay in hospital, or in the community as they carry out their activities of daily living. Whilst the two examples of chronic diseases given earlier in this paper show patient groups that may be monitored in the home, the hospital setting is one that also deserves special mention.

At present, patients in hospital receive monitoring of various levels of intensity ranging from intermittent (four to six times a day in the case of those suffering with stable conditions), to intensive (every hour), and finally to continuous invasive and non-invasive monitoring such as that seen in the intensive care unit. This monitoring is normally in the form of vital signs measurement (blood pressure, heart rate, ECG, respiratory rate, and temperature), visual appearance (assessing their level of consciousness) and verbal response (asking them how much pain they are in). Patients undergoing surgery are a special group whose level of monitoring ranges from very high during and immediately after operation (under general anaesthesia), to intermittent during the post-operative recovery period. Aside from being restrictive and “wired”, hospital ward-based patient vital signs monitoring systems tend to be very labour intensive, requiring manual measurement and documentation, and are prone to human error.

We introduced earlier in this paper the concept of “at risk” population groups such as the elderly. With people in industrialised nations living longer than ever before and an increase in average life expectancy of more than 25 years, the size of this group is set to increase, along with their demand on healthcare systems[11]. Identifying times of susceptibility and ways of monitoring this “aging population” in their home environment is therefore very important, with one example of vulnerable periods being the temperate weather months. There is evidence to suggest that at times of the year where weather conditions are at their extremes (either very cold or very hot), these patients are at increased risk of requiring hospital admission[12, 13]. They are at risk because they are not able to seek medical help early enough for simple and treatable conditions, which eventually may lead to significant morbidity. An example of this is an elderly individual who lives alone and suffers a chest infection which he fails to identify and seek help for until the infection requires hospital admission, or even ventilator support. This could all be potentially avoided if the infection, or change in patient habit as a result of this infection was picked up early and antibiotic therapy initiated. Examples of how people behave differently at the onset of illnesses include a decrease in appetite, a reduction in movement, and a likelihood to stay indoors. When correlated with physiological vital signs measurement, this system has the potential to clearly identify those at most risk. It is an area where WSN (set up in the patient’s home) and BSN (on the patient’s body) may overlap in their applications.

This leads to the concept of an unobtrusive “home sensor network” to monitor an elder’s social health, which is being developed by several companies such as the Intel Corporation [14]. Whilst such a sensor network attempts to monitor social well-being by identifying the individual and the level of activity they are undertaking, it is easy to see how this network could communicate with a BSN relaying physiological data about the individual. Combined, BSN and ambient sensing would allow for a much better appreciation of the context in which the sensing is taking place.

TECHNOLOGICAL INNOVATIONS OFFERING PERSONALISED HEALTHCARE

In order to achieve the goal of pervasive monitoring, several research platforms have emerged. The first of these is to use external sensors in wearable in clothing either by integrating them onto a textile platform (European Commission “Wealthy” project) [15], or by embedding them into clothes with integrated
The development of implantable sensors offers BSN what is perhaps one of its most exciting components. The European Commission project “Healthy Aims” has been focussing on specific sensor applications namely for hearing aids (cochlear implant), vision aids (retinal implant), detecting raised orbital pressure (glaucoma sensor), and intracranial pressure sensing (implantable pressure sensor) [25]. Other implantable devices include Medtronic’s “Reveal Insertable Loop Recorder”, which is a fully implantable cardiac monitor used to record the heart’s rate and rhythm at the time of unexplained fainting, dizziness, or palpitations. The device provides the clinician with an ECG that can be used to identify or rule out an abnormal heart rhythm as the cause of these symptoms [26]. CardioMEMS is a company that produces an implantable pressure sensor developed at Georgia Institute of Technology, that can pressure readings following implantation into an aneurism sac at the time of endovascular repair [27]. This provides a means of monitoring the repair over the following years. Finally Given Technologies has developed and endoscopy capsule that transmits images of the small bowel as it travels through the gastrointestinal tract [28]. All of these sensing technologies may ultimately form part of a wireless BSN.

Integrating sensors and therapeutic systems and thereby “closing the feedback loop”, is likely to play a major part in defining the role for BSN in clinical practice [29]. This is particularly well illustrated in the delivery of pharmacotherapy where currently drugs are administered at doses and frequencies that are based on average sizes, and metabolic rate. When considering that for an individual patient, who has an individual size and metabolism, this optimal dosage is likely to vary considerably from the “average”, it is clear that individualised dosing is preferable. In addition to this, a patient’s drug requirement may temporarily change during an illness, or for example when they are on other medications such as antibiotics. Whilst under dosing in these situations will result in inadequate treatment (for example seizures in patients on anti-epileptic medication), overdosing will result in an increased risk of the patient suffering unwanted side-effects. Drug-delivering feedback loops consist of miniaturised sensors that continuously monitor a drug’s effect and through medical control algorithms, adjust its delivery from miniaturised drug pumps. The dosage of the drug would therefore be individualised to the patient.

Whilst until now applications for the use of BSN in clinical practice have focussed around external and implantable sensors that lie relatively static within the body, it is the luminal organs such as blood vessels, gastro-intestinal tract, urinary tract, ventricles of the brain, spinal canal, lymphatic, and venous systems that offer the greatest opportunity to sense acute disease processes and monitor chronic illness quickly and efficiently. As the accuracy of the sensors increases and their size decreases, it is in these domains that we would like to have the maximal effect on any disease process. Recent advances in nano-technology have meant that delivering sensors within these luminal cavities is for the first time a real possibility.

CONCLUSION
This paper highlights the scope for developing pervasive healthcare systems taking into account the clinical drive, technological innovations, and socioeconomic benefits of such systems. Although proprietary designed wireless sensor networks offer some solutions to the problems of health monitoring, it is clear that a specialised “Body Sensor Network”
platform offers the opportunity to monitor human beings in a way that has not previously been possible. This truly “ubiquitous” and “pervasive” patient monitoring system will in the first instance increase our knowledge of disease processes, and will later on allow us to accurately monitor its progress.

REFERENCES