A Wireless Home and Body Sensor Network Platform for the Early Detection of Arthritis

A. Haroon, P. Fergus, A. Shaheed, M. Merabti

Networked Appliances Laboratory
School of Computing and Mathematical Sciences
Liverpool John Moores University, Byrom Street, Liverpool L3 3AF, UK.
Email: A.Haroon@2006.ljmu.ac.uk, P.Fergus@ljmu.ac.uk, A.Shaheed@2006.ljmu.ac.uk, M.Merabti@ljmu.ac.uk

Abstract: Information and communications technology influences many of the activities we perform on any given day. Through the widespread availability and use of consumer electronics we have almost augmented ourselves to permanently form part of technology. This has provided a platform capable of supporting fluid information flows anytime and anywhere and has opened up great opportunities across many sectors. However, it is perhaps the healthcare sector that may offer the greatest rewards. Now that people have permanent links to digital services new and novel applications can be developed, i.e. preventative medical services to help fight debilitating illnesses, such as arthritis. By employing real-time monitoring and analysis patients can be guided, based on their daily activities to prevent or mitigate the effects some activities may have on the body. In this paper we explore this notion and provide a framework to allow real-time monitoring of arthritic conditions in the home. The aim is to embed devices (inner and outer body sensors, including home sensor networks) to collect data that can be used to analyse activity around body joints (progressive destruction of cartilage and bone) and inform patients about aggravated activity. We have successfully demonstrated the applicability of our approach using a working prototype system.

Keywords: Sensors, Sensor Networks, Networked Medical Devices, Networked Appliances, Home Networking, Real-time Monitoring, Preventative Technologies.

I. INTRODUCTION

Technology now plays a big part in all the activities we perform in our everyday lives. Whether this is for communication, information sharing, or entertainment, technology underpins all these activities. With the ubiquitous deployment of wireless communications we now have the ability to contact devices globally and use their services. This has made it relatively easy to form closer relationships between people, opening up greater opportunities for new and novel applications, i.e. personal healthcare. The home already provides a number of different digital services and health applications are beginning to emerge that exploit these services. Despite the huge benefits this promises to bring home healthcare is still relatively unexplored. Partially, due to technology simply not being available and mostly because it is a risky step to take. Nonetheless, over the last several years this has changed where a typical home is now equipped with many different communication protocols and health and networked consumer appliances. Albeit, many solutions are deployed in an ad hoc and informal way but the likelihood is that this will change.

This presents an ideal opportunity to exploit technology for the purpose of preventative
medicine and care. There are good reasons for doing this. Perhaps most importantly is the fact that conditions are more often than not only detected when the effects of diseases are irreversible. For example, debilitating illnesses such as arthritis, often diagnosed in later stages of cartilage and bone damage, have been found to be on the increase. In the US reportedly 27 million adults have clinical osteoarthritis making it a high ranking degenerative or aging disease [1]. Considerable financial strain is placed on already pressed health services, which is further exacerbated by the fact we are living longer.

care to make compensatory changes to help avoid long-term damage.

Consequently, the motivation for this research is to embed devices, which include inner and out body sensors and home sensor networks to collect and distribute biophysiological data for the purpose of diagnostics and prevention of medical conditions. Our research provides the beginnings of a new and novel platform that could help dramatically improve the quality of life for people suffering from arthritis. We have successfully developed a working

II. BACKGROUND AND RELATED WORK

Rheumatoid arthritis is a chronic systemic disorder characterised by autoimmunity, infiltration of joint synovium caused by activated inflammatory cells, synovial hyperplasia, neoangiogenesis and progressive destruction of cartilage and bone. Patients suffering from this condition often have a higher risk of premature mortality - coronary-artery disease being the most prevalent attributable cause of death [2]. Controlled studies have shown that extra-coronary [3-5] and coronary atherosclerosis [6] is accelerated through rheumatoid arthritis, but the underlying causes are unclear.

Whilst these are alarming figures the number of arthritic patients could potentially be reduced through awareness. It is difficult to monitor or provide advisory services to all individuals however by exploiting technology there could be a way to deploy preventative measures. The challenge is to harness the power of technology, particularly those in the home and ubiquitous communication infrastructures, such as the cellular network, to monitor signs of progressive destruction of cartilage and bone. The challenge is to not use technology to cure arthritis - this is not possible - but to use it to provide an early detection system. Achieving this would empower the patient through self-prototype in which body sensors on the hand can be discovered and used to receive movement data relating to the hand and its digits for use in medical diagnostics.

The remainder of this paper is structured as follows. In Section II we introduce the background and related work. In Section III we provide an overview of our proposed framework and in Section IV we present our implementation. In Section V we provide an evaluation of our implementation before concluding in Section VI.

This disease affects between 1 and 2 percent of the population worldwide and is most common amongst middle-aged women [7]. Although the exact cause of rheumatoid arthritis is still unknown, insights into its pathogenesis have confirmed the role of proinflammatory cytokines (e.g. tumor necrosis factor alpha (TNF alpha), interleukin 1 and interleukin 6) in disease pathways [8]. Current treatments target the inflammatory systems with disease modifying antirheumatic drugs (DMARDs; e.g., methotrexate) or biological agents. The biological agents inhibit the action of cytokines (e.g. TNF alpha or interleukin 1) or limit B-cell function or T-cell co-stimulation, especially in combination with methotrexate [8-11]. The need to cure or eradicate arthritis is two-fold - it addresses
minimise physical disability and secondary health conditions.

Given that there is little consensus on what causes arthritis, it may be appropriate to focus on preventative measures in parallel with biological treatments. If arthritis was prevented there would be less need to rely on the use of drugs to treat the condition. This is where technology could perhaps help. Advances in home networking have lead to the deployment of networked medical devices and services [12]. Medical devices themselves have become increasingly more network-enabled and now support better capabilities. There is a trend to exploit such devices in a none bespoke way by including non-medical networked devices for the purpose of specialised treatments - for example a Wii Controller could be used in a medical application to assess movement and human behaviours relating to mental disorders [13].

Extending this idea further more detailed information could be obtained through new and emerging body and sensor networking technologies. Many have foreseen this gap in the market and are already building on the notion that the environment will become more finely augmented with information-bearing devices, such as sensors. For example, in-home assistance in smart medical homes will help the aging population by providing memory enhancement; home appliance control; data collection; and emergency communication services [14]. Wearable sensors will serve to collect data, which could be used by services and mined as a data source for next-generation clinical trials. There are many difficulties in achieving this, i.e. networked appliance interoperability; real-time data processing; reliability; and device heterogeneity [15]. Perhaps a natural path of enquiry is the convergence of the two disciplines allowing advances from both to be mutually beneficial. What is clear is that this will undoubtedly become a multidisciplinary venture where no single domain will redress all problems.

Sensor networking research is clearly a very active topic in both the home and medicine, with estimates already reaching $18 billion on BioMEMS research in 2005 [16]. Researchers argue that investment is significantly influenced by a drive to revolutionise healthcare to allow pervasive and continuous monitoring of real-time physiological conditions. There are many motivating factors for the use of biosensors. For example, sensors have already been designed to collect routine data, such as Wireless ECGs, which would otherwise require trained medical practitioners and site-specific technology. Using sensor technology to obtain bio-physiological data in this way is seen as a considerable cost saving to the medical organisation and at the same time an advanced means of processing and reacting to real-time data. Again as is the case with many other platforms under consideration implementation is plagued by a large number of technical challenges. Specifically: heterogeneity between devices and sensors; interoperability between the numerous wireless protocols available; reliability; context; and real-time adaptation.

Despite this long list of challenges, we cannot ignore the potential benefits this technology could bring, and the fact that a new breed of networked medical device has great potential in moving from reactive to preventative medicine.

III. Framework Overview

The motivation for this research rests on a number of issues. Although numerous network protocols have been developed the issue of interoperability has been the main problem for industrial and academic researchers. In this project we aim to mitigate (tone down, ease, moderate) the many interoperability issues that currently exist. One of the ways in which we aim to address this is through an abstraction layer designed to hide many of the current interoperability issues.
Of particular interest is the growing area of BioMEMs and their integration into existing home networks for the purpose of deploying medical services to facilitate the improvement of patient healthcare. In this project, different wearable sensors are used to collect data, for use by healthcare services, and mined for next-generation clinical trials. These sensors are designed to monitor, collect, and transfer data to a medical set-top box linked to remote medical services in much the same way your television is linked to entertainment services. Building on home networking standards (KNX, OSGi, UPnP, HomePlug, and many more) they can be extended to incorporate home medical devices and body sensor technologies. Home networks consume these devices for exploitation by medical applications to provide healthcare services that support the patient. Figure 1 illustrates two different environments (home and medical facility) where sensors (body and home) can be used by medical practitioners, remotely, to collect data for health diagnostics.

The overall system architecture shows that data travels from sensors, via a set-top medical box and wide area network, to medical practitioners. BioMEM sensors situated on and in the body of patients can support the data link between the home and medical services. Sensors embedded throughout the home provide short-range multi-hop communications with the set-top box and allow the patient to freely walk around the home. There may be instances where the patient moves outside of the communication network, i.e., goes to the shops. In this instance, sensors on the body detect this change (break in communications) and begin to store data on the sensor itself. When communications are re-established, all data stored on sensors is transmitted to required medical services.

Data can be read and written to remote healthcare services or locally to the sensors internal flash memory. The first mode is used when sensors have a connection to the base station via its network and the second is when connectivity is lost.

The base station acts as a link between the sensor network and the set-top box. And the set-top box forms a link between patients and medical services. Queries can be created and sent in both directions - from the sensor to medical services and vice versa. Using the set-top box and sensors, patients can ask questions regarding their medical condition, for example, progress checking an arthritic hip using motion sensor data. In the opposite direction, clinicians could perform real-time assessments in order to assess, alter, or predict future treatments based on the information stored in data sources.

A number of data analysis functions can be performed, such as Kalman Filtering [17] or simple statistical analysis. Data is generally stored in medical service data stores. Data pulled from these stores may be processed and analysis functions applied dependent on the clinicians or patient's application requirements. Data could be sourced to multiple systems in parallel given that difficult medical facilities would use the same data for different conditions. Furthermore, data replication and fault tolerance functionality is fundamental for the deployment of medical services, thus many different sources would be desirable for this purpose. The proposed framework is flexible and extends our previous work [12] to provide a set of framework services to improve patient health as well as provide a set of tools for physicians and doctors from different medical domains. The data source can be connected to central hospitals or remote sites to monitor the patient's medical condition(s). This same source directly used by medical practitioners to communicate with patients using telemedicine equipment.
IV. IMPLEMENTATION

The implementation has been built on top of home networking standards and techniques we have already developed [12] to include small body and environment sensors. In the prototype SunSPOT sensors have been used to allow data to be collected from the patient in all parts of the home. Based on the ZigBee standard SunSPOTs provide basic sensing functions and are fully extensible through digital and analogue IO to create any conceivable sensing device (EEG, ECG, Galvanic Skin, and Respiratory) - this means that SunSPOT sensors can also be attached to the body. A set-top box has been developed as a service on the network, designed to collect all sensor data. Data is stored using a mySQL database and in the event of connections being unavailable data is written to the SunSPOTs internal flash memory - upon re-connection the data from the flash memory is written to the database.

All SunSPOTs communicate with each other over a multi-hop network allowing data to be transmitted over a large radius. Any number of SunSPOTs can reside between source and destination sensors to create a network of mesh routers. Free range SunSPOTs (sensors that have sensing capabilities), i.e. body and environment sensors broadcast datagram packets to their nearest SunSPOT neighbour in order to try and establish a connection with that SunSPOT. This provides support for the required multi-hop methodology. The number of hops through which SunSPOTs can relay messages can be set to 15 hops. Each SunSPOT receives information from the surrounding environment and then relays it to either the base station (note that the base station is the sensor connected to the set-top box that allows it to form part of the sensor network) or the free range SPOT when multi-hop functionality is required.

In our test setting data is received from a hand fitted with the 5DT Data Glove which contains its own motion sensors as illustrated in Figure 3. The glove has been connected to a notebook computer, which also has connected to it a SunSPOT base station. The glove API is written in C, which we have adapted to provide a TCP/IP port. This allows a desktop application written in Java (used to program the SunSPOTs), to connect to the TCP/IP port and receive streamed data.

![Figure 3](example_image.jpg)

**Fig. 3 Example of Arthritis Test Bed**

The Java SunSPOT application connects to the server port provided by the 5DT Data Glove and requests all data from the glove sensors. This results in a continuous stream of data from the glove, via the mesh multi-hop sensor network to a 3D virtual representation of a hand and based on the data received the virtual hand mimics the same action.

V. EVALUATION

The proposed framework has been designed, tested and evaluated using several criteria. The focus was on implementing a sensor glove, connected to our framework, to collect movement data from a patient with arthritis, as illustrated in Figure 5.

The used was 5 to cover a distance of 35 meters. At the opposite edge of the network a second notebook was used to hold the 3D visualisation. A base station connected to this notebook was equipped with a data listener to collect streamed movement data from the glove and used to animate, in real-time, the 3D hand model.

In our first experiment the framework was tested with multiple data transfer rates to identify throughput and power consumption. Each packet size was 105 bytes
- all movement values for a particular frame. When transferring a single packet to a free range sensor up to 8 meters the results show that 0.0002 (%) of total power available is consumed. Increasing the data rate to 10 packets per second and running the streamed data over the network for a period of 1 minute, the results that the total power consumed is 0.0257 (%).

Increasing the distance to 16, 24, and 32 respectively and the time to 2, 3, and 4 minutes we find that total power consumption second where sent. of the complexities it currently supports. For example, more flexible mechanisms need to be developed to enable interoperability between different sensors; better case studies are required; more evaluation criteria is needed; and the investigations into data compression and better transfer mechanisms are fundamental. There is also a need to perform clinical trials. The results for power consumed over distances between 10 and 40 meters when 1000 packets per second where sent. The experiments provide valuable information for the deployment of any medical sensors and networks in the home environment. They demonstrate that technology does make it possible to consider new and emerging technologies for the purpose of healthcare real-time monitoring.

VI. CONCLUSIONS AND FUTURE WORK

In this paper we have presented a novel framework that describes how BioMEM technology could be used to provide medical services within the home. By equipping sensors, such as SunSPOTS, bio-physiological functions can be created to extract information from patients for medical analysis. This information can be transmitted, via sensor networks and ubiquitous communications, to medical facilities and used to diagnose, predict and administer treatments for any number of medical conditions. In this paper we have successfully demonstrated the applicability of our approach for the treatment of arthritis using a working prototype. The prototype was evaluated against power consumption and distance; and time verses power consumption - the results demonstrate the applicability of our approach.

There is still a great deal of work to be done. The framework needs to be abstracted to represent efficiently many

REFERENCES
