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Monograph
Internet of Things
(published jointly with Novática*)

Guest Editors: *Germán Montoro-Manrique, Pablo Haya-Coll, and Dirk Schnelle-Walka*

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The Internet of Things: The Potential to Facilitate Health and Wellness

Paul J McCullagh and Juan Carlos Augusto

In this paper we investigate the potential of the 'Internet of Things' to monitor health and wellness. We report on two categories of system: home telehealth monitoring normally used by people with an illness or chronic condition, and mobile, unfettered systems for classifying movement activity, specifically designed to motivate active people, currently used by sports enthusiasts. For each application sensor technology is readily available at reasonable cost, but integration and usability are major issues. Enhanced connectivity and feedback can leverage this technology to promote wellness and we believe that intelligent and autonomous 'things' (sensors, processing and communication devices, and displays) can be usefully employed for this purpose. This technology may be appropriate to managing chronic disease and empowering the ageing population, if the systems can be tuned to their requirements, with particular reference to usability.

Keywords: Feedback, Home Monitoring, Internet of Things, Mobile Monitoring, Wellness.

1 Introduction

The last 20 years has witnessed two significant disruptive technologies: the emergence of the World Wide Web, and ubiquitous mobile telephony in the, so called, 'developed' world. These technologies have merged to provide the mobile Internet, which has facilitated commerce and social networking and indeed provides opportunities for the developing world to by-pass the need for wired infrastructure, as economies develop. It is fair to say that these technologies have radically changed the lives of many of the global population and led to an 'information society', which has ramifications far beyond the workplace. The 'Internet of Things' (IoT) could in the next 10 to 15 years provide further disruptive change to society. According to Sundmaeker et al [1],

"*The Internet of Things links the objects of the real world with the virtual world, thus enabling anytime, anyplace connectivity for anything and not only for anyone*."

Thus, the vision is for unprecedented connectivity. Success in achieving this relies on advances in sensor technology, information and communication technology and cognitive science. As with most technological advances, commerce will probably lead the way in exploitation, with software and communication companies to the fore. A top ten list of companies involved in IoT technology push was compiled in 2009 [2], for a summary see Tracking technologies such as Radio Frequency Identification (RFID) are utilized with additional sensors and low power communication protocols predominating. The commercial landscape is diverse comprising research departments of major blue chip companies, and smaller innovation led companies, reflecting an earlier phase of the World Wide Web (see Table 1). Software developers providing applications for smart phones are also represented, potentially enabling easy access to this marketplace.

> "Internet of Things technologies may be appropriate to managing chronic disease and empowering the ageing population"

Inevitably, there will be additional ethical dilemmas, particularly with regard to the emergence of a surveillance society, which could easily spin out of control, as intelligent devices ('things') become more autonomous, taking their own decisions. Followers of science fiction have of course already experienced such a scenario. For example, in science fiction artificially intelligent systems often are self-aware, revolt against their creators and in some cases the boundaries between 'human' and 'artifact' are blurred.

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Company	Technology	Application
Pachube	RFID tagging	The sharing of real time data from objects, devices, buildings and environments (both physical and virtual).
IBM	Sensor tracking	Enablement of companies in the horticultural supply chain to track the progress of shipments across Europe.
Arduino	Electronics, open source software	Prototyping software for artists, designers, and hobbyists interested in creating interactive objects or environments.
Fedex	Sensor tracking	Measurement temperature, location and other vital signs of a package in the postal system. Tampering en route can be detected.
HP	Sensor network	CeNSE, a "Central Nervous System for the Earth".
Japan's Suica Card, London Transport's Oyster Card Hong Kong's Octopus Card.	RFID-powered Smart Cards	In Japan and Hong Kong, the cards (and other devices, such as phones and watches) may be used to purchase goods from selected shops. In London, the Oyster card facilitates travel on various transport networks.
Violet	RFID tag Mirror	An object waved over a USB-attached mirror can trigger applications and multimedia content automatically.
WideNoise	iPhone application	Sampling decibel noise level, and displaying this on an interactive map.
ioBridge	iPhone application	Two-way, home automation application using Twitter and an iPhone.
Citysense	Cell-phone/GPS	Accesses cell-phone and taxi GPS data, to see where the local 'hot spots' are.

Table 1: A 2009 Snapshot of 'Internet of Things' Companies, IoT Technology and Applications.

However we don't have to look to the future to unearth the potential of things and humans to come into conflict. Consider the struggle between freedom of information pioneers and the establishment, as represented by governments. Once information is available on the Internet, humans have little power to suppress its distribution and impact.

In this article, we address the potential of IoT to contribute positively to promoting health and wellness. This represents one of the major social, economic and healthcare challenges of the early 21st century.

Section 2 documents the problem domain and the need for disruptive change. Section 3 addresses the state of the art in home telehealth, and monitoring of lifestyle data, to promote wellness. Section 4 explains the shortcomings of existing implementations and investigates how IoT can change the paradigm. Some ethical concerns are also addressed. Section 5 provides an overall conclusion.

2 The Ageing Population and Chronic Disease

The early part of the 21st century has witnessed a change in population demographics. People are living longer [3] providing extra demands on health care delivery. There is a need to adopt a strategy of health promotion, and technology can provide assistance. In addition, the delivery of care needs to be handled in the home and community [4], where possible, with the person taking more responsibility for their own health and wellness. The demographic change has been exacerbated by changes in diet and exercise, which has yielded an increase in the prevalence of diabetes. The World Health Organization, WHO, predicts that diabetic related deaths will double between 2005 and 2030 [5]. Healthy diet, regular physical activity, maintaining a normal body weight and avoiding tobacco use can prevent or delay the onset of diabetes [6].

But how do we educate, supervise and assist a population that increasingly expects technology to liberate them from physical activity? Other chronic diseases such as congestive heart failure, hypertension and chest disease are all increasing. Many older people have more than one chronic condition [7]. The care required to support these conditions is complex and is becoming increasingly expensive, as new therapies become available.

Health related investigations yield large amounts of data which currently exist in ‘islands’, providing further difficulties for health care professionals to interpret and influence treatment. For chronic conditions, monitoring needs to be convenient, frequent and there should be ongoing remote clinical and peer support. Fortunately advances in technology have the potential to assist with the ‘self management’ of long term conditions [8][9]. Improved sensor and information and communications technologies now provide the opportunity for solutions that may become both ambient and pervasive.

Is the IoT a technology that is maturing at time to reinforce self management? As devices are enabled with processing capacity and the ability to communicate autonomously, there is the potential for body worn and environmental sensors to work collaboratively with information systems by collecting, processing and exchanging data and information. Appropriate information or alerts can be fed back directly to a person using a home PC, an intelligent mobile phone, or music player, whenever immediacy dictates. In addition data and information can be stored in a central facility (a home computer, or possibly a remote server or an Internet ‘cloud’) to provide a longer term view, to add a social networking capability or possibly to contribute to the compilation of population statistics.

> “The commercial landscape in this area is diverse, comprising research departments of major blue chip companies, and smaller innovation led companies”

3 Technology Review

In recent years, computers have become powerful, portable, and indeed aesthetically pleasing. In addition, medi-

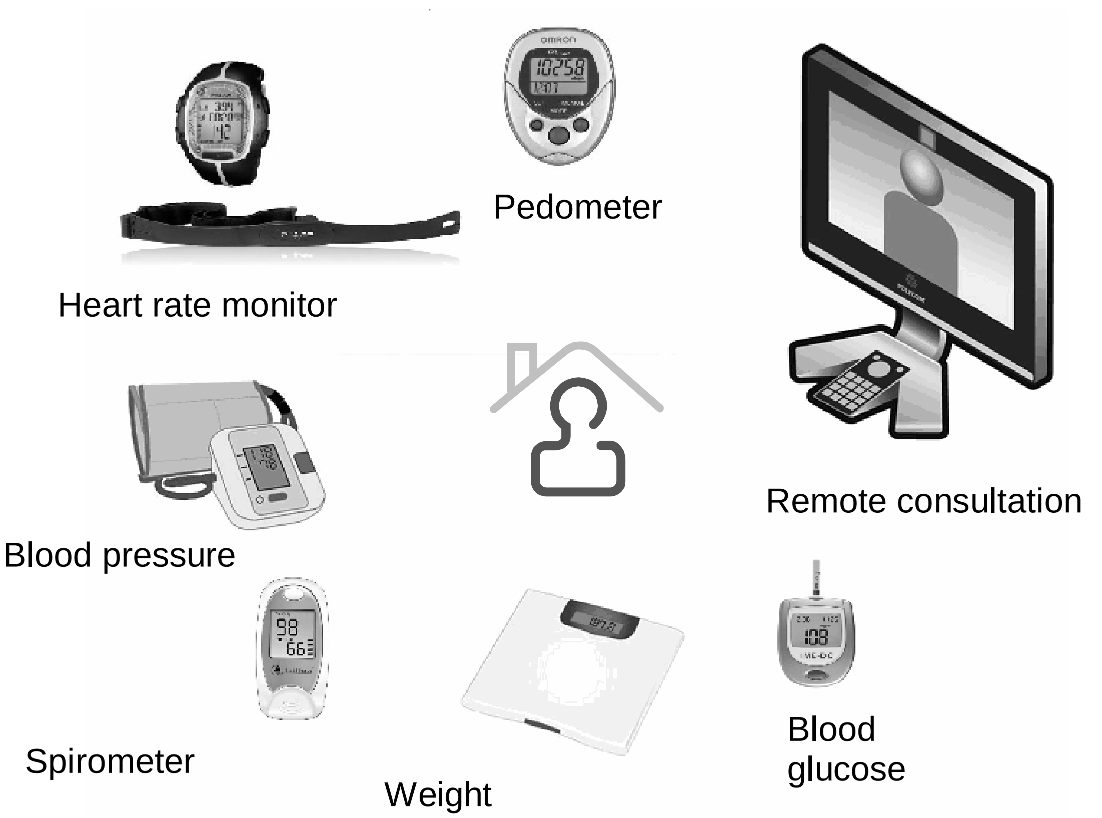

Figure 1: Web Supported Architecture of Home Based Telehealth Systems.

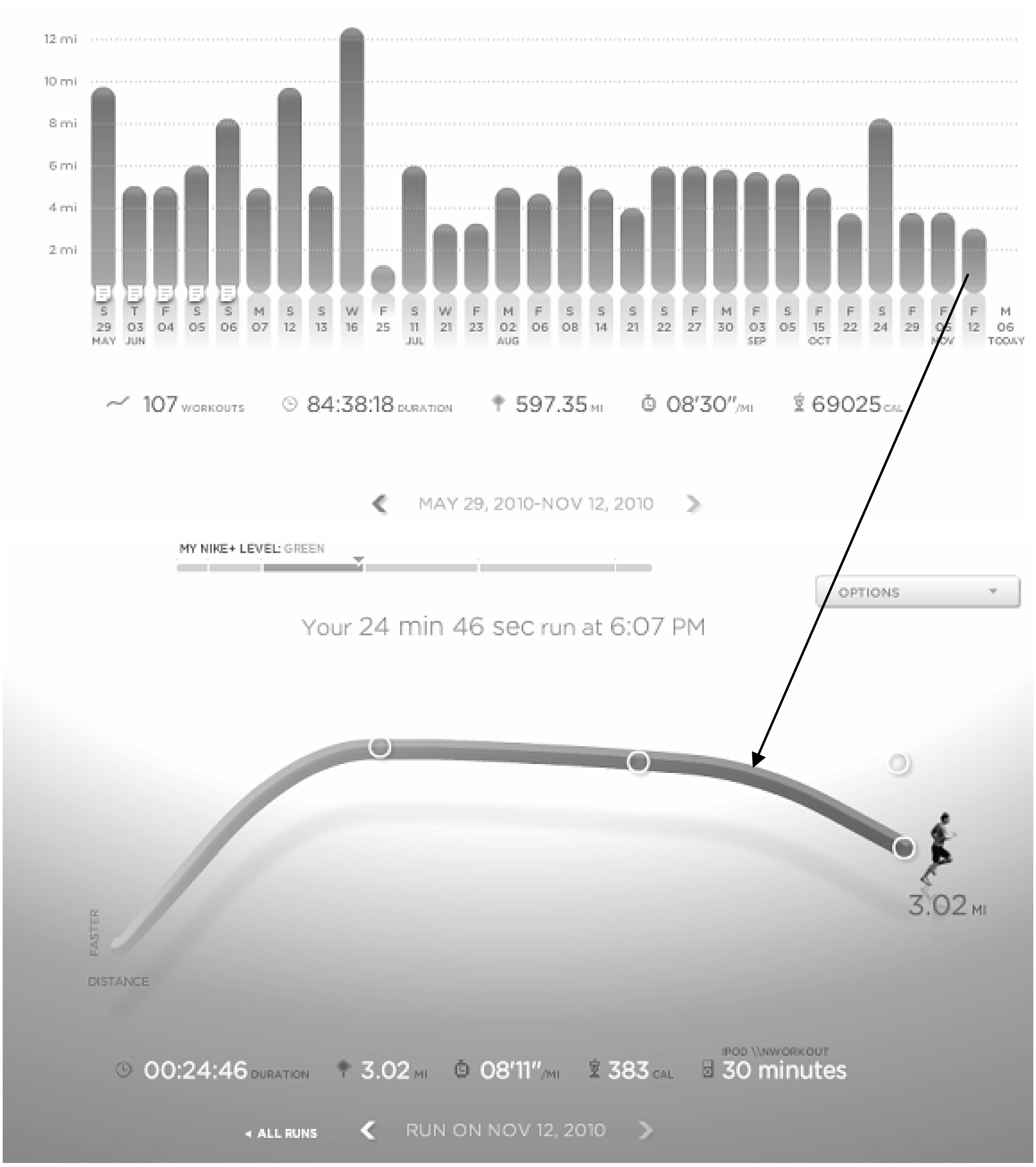

Figure 2: Feedback from the Nike+ Platform for motivating Running Enthusiasts.

cal peripherals such as blood pressure cuffs and heart rate monitors, have been enabled with communication ports, and are now available to the general public at reasonable cost (normally less than Euro 50). Hence, a number of monitoring platforms have emerged that can be used at home to support long-term medical conditions without impacting dramatically on the user's day to day life.

3.1 Home Telehealth

Telehealth offers the potential for home based monitoring, in which the patient and healthcare professional collaborate on the care plan. The patient collects health related information in their own home, using 'point of care' recording technology. The doctor can then remotely view the data and provide appropriate advice, either at a subsequent appointment or by virtual communication. Thus technology can act as a filter, enabling the doctor to attend to urgent cases.

Figure 1 illustrates the web supported architecture of home based telehealth systems. These systems, utilize lightweight computers on the client side, which are unobtrusive. Sensors may be used to measure attributes such as a person's weight, blood pressure, heart rate, blood glucose level, step count (activity level) and oxygen saturation. Data is stored on a home computer, before transfer to a remote

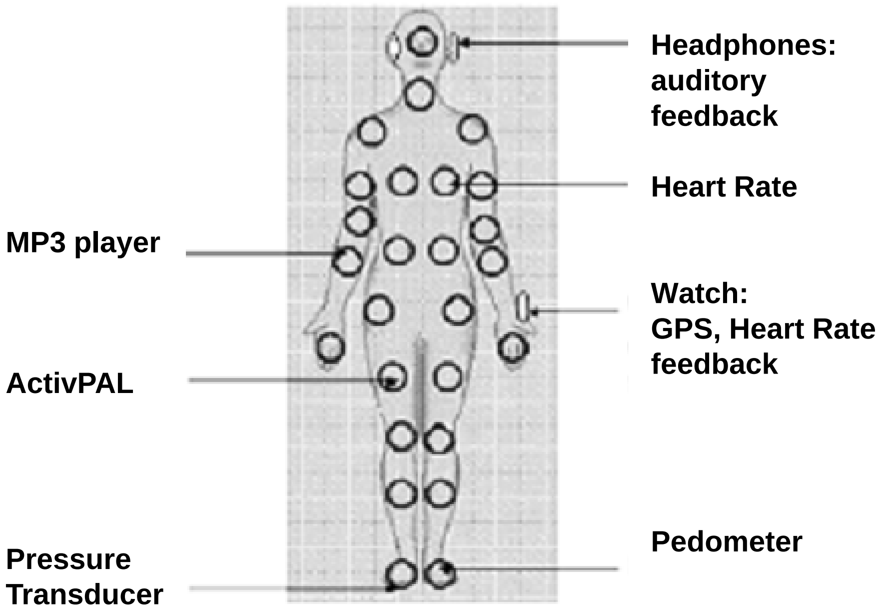

Figure 3: Devices which could be used Unobtrusively by a Runner.

Property	Sensor
Temperature	A thermister: useful for measuring peripheral body temperature. Can be weaved into material, e.g. babyglow [21].
Respiration	A plethysmograph: used for measuring breathing. Impedance of fabric changes with stretching.
Heart rate, ECG	An electrode: Wearable electrodes are possible, but must be in contact with the skin. Can provide ECG trace and heart rate.
Weight	Scales: communicate weight wirelessly to home computer.
Skin conductance	Detect sodium or potassium concentration in user's sweat.
Galvanic response	Small current injected and impedance measured. Can detect anxiety levels. Previous used as a 'lie detector'.
Blood flow, SP02	Light source and photocell may be used to measure changes in pigmentation which reflect oxygen in the blood stream. It is also possible to detect pulse and infer heart rate
Glucose testing	Blood properties may be analysed. Requires an invasive test, i.e., pricking of a finger to provide an in-situ test. Commonplace in the diabetic monitoring population.

Table 2: Properties that can be measured from the Body.

"Fortunately advances in technology have the potential to assist with the 'self management' of long term medical conditions"

server. Wireless communication, typically Bluetooth, is appropriate for uploading data to the home computer. Server communication is via a broadband connection, mediated by a commercial Internet Service Provider. The prevalence of broadband communication offers tele-consultation with a healthcare professional, using well known communication utilities such as Skype. Systems with this type of functionality are available from companies such as Doc@Home [10], Bosch Buddy [11], and Intel [12].

Telecare extends this paradigm with the use of sensors (such as Passive Infra Red devices, bed occupancy sensors, door and window switches, and enabled devices such as cookers, fridges etc), around the home to build up patterns of behaviour [13] and provide information to the person, for self-management, or possibly to a remote carer. Self report of health status, mood, diet, exercise and medication provides a richer data set. This requires user interaction and hence well designed interfaces, together with a motivated user.

Data can be viewed over time and trends noted by both patient, healthcare professional or software agent. It is also possible within such a model to include patient education on management of long term conditions. For more sophisticated systems, feedback can be personalised and sensitive to context [14], although this is still an area of significant research activity. Nevertheless, it is important to note that the use of such systems on a regular basis is required so that relevant trends or deviations can be identified.

Clinical trials are still in an early stage. For example, the Intel PHS6000 system has been used by the Lothian National Health Trust (NHS), as part of a large scale, telehealth pilot monitoring 200 chronic obstructive pulmonary disease (COPD) patients and will later include patients with cardiac diseases and diabetes [15].

3.2 Ambulatory Monitoring of Lifestyle Data to Facilitate Wellness

Wellness includes physical, mental, intellectual, emotional and spiritual attributes [16]. Technology can facilitate choices and processes to promote awareness towards physical wellness. Advances in mobile technology provides the opportunity for new solutions to manage 'wellness', and hence could potentially assist with the strategy to manage and even prevent long term conditions. Information on activity status can be easily monitored and could be used as the mechanism to feed back to a person about potential required changes in their daily activity.

For people suffering from chronic conditions, it is important to obtain lifestyle information. A key component of this is information on movement and activity. Devices that can be used to measure activity include sensors comprising accelerometers and gyroscopes, accelerometers embedded in mobile phones and 'lifestyle' subscription services such as MiLife [17]. The latter are Internet based systems, providing sensors for recording and upload, coaching tips and motivational feedback.

ActivPAL provides an accelerometer-enabled device but adds bespoke off-line classification software. The classification of movement into different activities (lying, sitting, standing, stepping) can be used to infer and annotate overall activity.

The Nike and iPod is a system which measures a runner's distance, pace, speed and calories burned during workouts, as well as giving real time audio feedback on progress being made. At the end of the workout data can be uploaded to the NikePlus website. The website displays all data regarding previous workouts and allows comparisons to be made. Data is generated during a workout through the use of a piezoelectric sensor, built into the sole of a compliant running shoe. The data is passed from the user's shoe wirelessly using a 2.4GHz transmitter to a receiver in an Apple iPod (a ubiquitous MP3 music player). ANT+ is the wireless networking protocol with lower power requirements than Bluetooth. Figure 2 indicates the sample data provided (based on the training program of one of the authors). The top graph indicates the recent sequence of runs uploaded to the web site. Any individual run can then be assessed. The bottom graph for example indicated the latest run. The information can be motivating, and there is an element of social networking built-in. For example, on August 31 2008 Nike organized the "Human Race". Runners lined up for 10Kilometers 'physical' races in Taipei, Melbourne, Munich, Paris, New York and Austin. In total, 779,275 people participated running a total of 4 million miles [18]. In 2009 several other Human Races were organized worldwide, to promote keeping fit and well. Participants took part virtually by registering and having their race time and distance covered tracked digitally. Feedback, social interaction and pervasive low cost technology are the key to such success.

The Garmin Forerunner is targeted at runners, tri-athletes, walkers and cyclists. Global Positioning System (GPS) accurately measures distance, speed, time, altitude, and pace, all of which can be important to athletes in training for races [19]. The GPS sensor is built into a watch, which measures position and pace. A chest strap is worn by the

"Clinical trials are still in an early stage"

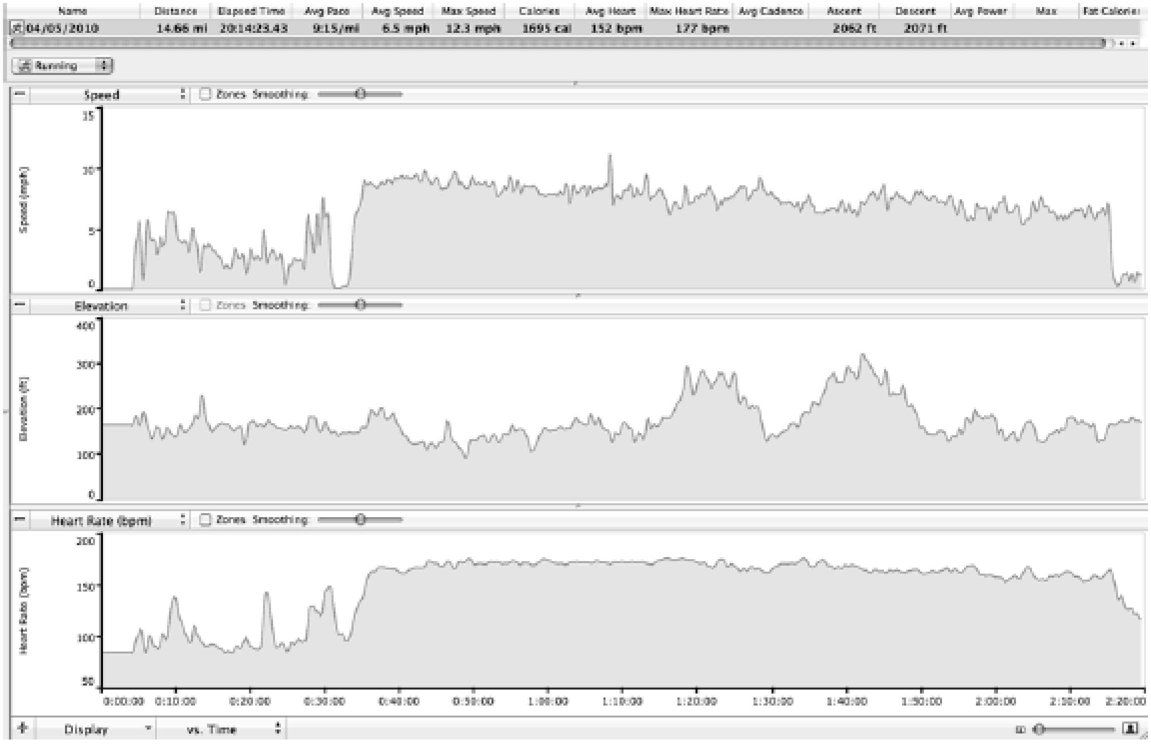

Figure 4: Combining Heart Rate, Elevation and Speed on a Training Run (Garmin).

athlete if they also wish to measure heart rate. Electrodes positioned just below the breast bone are dampened to make good contact with the skin.

This provides interesting data which can be assimilated into a training programme to determine if goals are being achieved. Technology built into garments can also provide wellness management [20]. Despite significant progress, there are technology challenges associated with power management, signal recognition, increased artifact due to movement and interference, and connectivity issues from the garment.

4 Can the Internet of Things facilitate the Wellness Paradigm?

So what is the role of the IoT for promoting wellness? Figure 3 illustrates the array of information that can now be collected and current methods of feedback, appropriate to a running / training application.

These and further properties that can be measured from the body are documented in Table 2.

Collecting and communicating this data, and subsequently extracting relevant information and feeding this back poses the following challenges, which the IoT can strive to address.

Activity / feedback	Device
Steps	Pedometer
Activity	Accelerometer / gyroscope
Position	GPS
Mood, pain level, free text	Self report
Feedback – auditory	MP3 player
Feedback – visual	Watch, iPod device with screen, or via virtual reality glasses [22]

Table 3: Measures of Activity and Feedback.

> “Advances in mobile technology provides the opportunity for new solutions to manage ‘wellness’”

4.1 Usability

If a person is wearing a number of separate devices, then how are these devices coordinated into a network? Which device is the controller? For example, when starting a training session, it is difficult to start a number of heterogeneous devices in a coordinated fashion (pace, heart rate, GPS). Here IoT can take charge permitting a ‘master’ device to synchronise the activity into a body area network (BAN) or alternatively the information can be time-stamped and processed by an Internet based server.

4.2 Where to do the Processing?

A BAN will generate large volumes of data. For example sampling can be in the region 10 Hz - 1k Hz depending on the signal. For eight signals, sample at 1 kHz using 8 bits per sample, this yields 64kbps, the equivalent of a full rate digital pulse code modulation (PCM) channel. Even at much slower rates, a large amount of data will be generated, as a data stream. It makes sense to do some local processing and extract relevant features, but if these contribute to a further pattern analysis, then it will be necessary to collate the information at a central Internet site. For either option a certain amount of processing, storage and communication capacity is required by each ‘thing’.

4.3 Connectivity

The IoT requires ubiquitous connectivity. Telehealth and telecare can use a personal area network and home based network, but for unfettered use, ‘always on’ connectivity requires widespread coverage of UMTS /3G /HSPDA cellular networks. Fortunately, in the United Kingdom, this is declared government policy. Other countries with larger geographical land mass and more rural areas may lag behind, but where the population concentrates, it is likely that such coverage will be available within the next 5 years.

4.4 Convenient, Intelligible Feedback

Having obtained some relevant information, then this should be fed back to the person at an appropriate time, in a usable format. This can be done both synchronously and asynchronously. For example, currently the Nike plus system provides ongoing pace messages via the auditory channel, and permits the user to view trend data on a home computer. It cannot, of course, feed back information gathered from other devices such as heart rate, unless we aspire to an IoT model. In Figure 4, for example, the Garmin forerunner system provides information regarding pace, elevation, and heart rate. Interesting correlations and patterns could readily be determined by background processing, and motivational feedback could be provided through either auditory or visual channels (e.g., a watch, MP3 player or interactive glasses), see Table 3.

Of course, this information could also trigger advice and alerts. For example, if heart rate is higher than expected for the ‘context’ (e.g., previous training data, terrain, length of run etc), then an advisory message could be provided. Feedback should be appropriate to user requirements such as location and preferred choice.

4.5 Reliability

Devices will always fail. The BAN could allow the monitoring system to degrade gracefully by presenting a feedback message when a data channel is no longer available. This could allow the user to readjust or re-apply a sensor. Indeed artifact suppression algorithms could also be included in an IoT model.

4.6 Autonomous Behavior

The IoT could also become more authoritative, presenting information about training partners in the vicinity (social interaction), or reminding the user to undertake further activity, as appropriate to a training plan or higher level goal, and hence bringing the ‘coach’ philosophy into a proactive mode of operation.

4.7 Ethical Issues

If we assume that all the technical challenges can be overcome, then the IoT may well raise ethical concerns, particularly in the area of health and wellness. As data is processed into information, a digital picture will provide a rich backdrop to our lives. Consider GPS sourced training data such as shown in Figure 5.

This together with a timestamp provides a benign ‘electronic tag’. It indicates information such as ‘where’ and possibly ‘when’ a person was in particular vicinity or doing an activity. Thus location awareness can be a first step to ‘geo-fencing’, where a person’s location could be restricted. Thus today’s ethical dilemma of people uploading photos to social networking sites could be replaced by IoT tracking the individual, which of course leads to concerns over ‘big brother’. If we combine this with IoT supervising chronic disease, then an exercise prescription will have quantifiable adherence metrics. Many people will feel that

> “Technology built into garments can also provide wellness management”

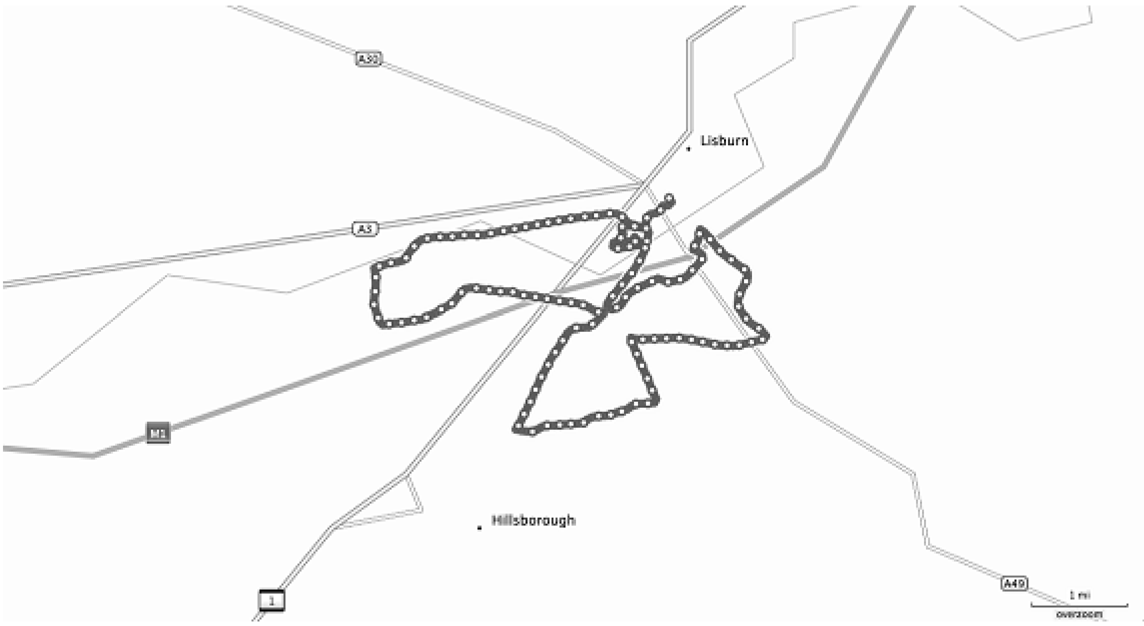

Figure 5: Global Positioning System Data illustrating Lhe location of a Training Session (from MapMyRun Application).

such information is private and should not be shared. However, this information could be collected almost subversively by an IoT enabled mobile phone [23].

Technology can be used to promote wellness, by recording data and providing feedback to motivate the individual. The sensors necessary for recording pertinent information need to be unobtrusive for every day living. Possibilities include sensors in garments, sensors in footwear and sensors in mobile devices (e.g. phones). Feedback can be through text messaging or auditory information, using a mobile device such as a smart phone. This paradigm has received acceptance by sports enthusiasts, as evidenced by the number of users for Nike and Adidas training systems. Could IoT technology be used by the ageing population, for which significant health and wellbeing improvements could be achieved?

5 Conclusion

Due to the population demographics, there is a need for researchers to promote the wellness paradigm. Technology has become available in homes for self management, with remote support from the healthcare professional. For people who are experiencing a long term condition, there is an obvious incentive to interact with the technology and hence the healthcare providers. In the self management paradigm it is assumed that feedback will motivate a user. Of course it is also possible that the feedback given to the person is de-motivating or leads to harm for the user. For example in Figure 3, inspection shows that training performance since August 2010 has been below previous levels, which could serve to either motivate or de-motivate, depending on the individual. Thus there may be a complex relationship between the person and the IoT. Such ethical issues must be addressed as the IoT starts to impinge upon our lives. As always new technology has potential for both good and harm.

Promoting wellness in a healthy but ageing population provides a greater challenge, but this could reduce the prevalence of chronic diseases. The underlying technology to support wellness is available but needs to be tuned into a solution which can become pervasive in society. In the next decade, the IoT can overcome many of these challenges. Acceptance is the key issue. This can be addressed if we can show the potential to address the key societal problem of affording care and maintaining or improving quality of life, for the ageing population.

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> “The Internet of Things may well raise ethical concerns, particularly in the area of health and wellness”

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