A Physical Basis for Ambient Intelligence
The Convergence of Biology, Polymers and Electronics Enabling New Design Approaches to Assistive Living

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Abstract. Innovation in materials drives new technologies - in the 1930's DuPont and ICI discovered and developed Nylon and Polyethylene polymerisation. Today, a new wave of conjugated conductive polymers is emerging, with electronic properties akin to Silicon with effects & interactions stemming from the electronic configuration within the material allowing them to be programmed, through their electron mobility, yielding conformable logic and memory devices. These active polymers are flexible, lightweight, transparent and solution processable, lending themselves to applications and opportunities in ambient assisted living, driving printed electronics and optoelectronics. This paper outlines the principles and provides initial examples of studies underway afforded by the physical basis for ambient intelligence, pursued through a P^3i Design Research Studio.

Keywords: Ambient intelligence, organic electronics, assistive living, creative design, design-science interactions.

1 Introduction

Ambient Intelligence (AmI) has emerged from ubiquitous/pervasive computing and the virtual 'internet of things' to a more tangible physical basis which, in general, follows Weisser's definition of human centred/needs driven technologies incorporating healthcare, convenience, information access, connectivity and generally making life simpler and more stress free [1]. The new drivers accelerating an ambient life environment are the emergence of conformable conjugated conductive polymers, i.e. electro, photo and bio active, capable of designed development to incorporate into objects, devices and interactive consumer products. Organic macro electronics

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began to make AmI into the embedded ‘visible invisibility’, anticipated in the mid 90’s and made into physical reality by the wave of new nanomaterials and active polymers now emerging. Combining information, intuition and intelligent structures, they bring about the missing link in most analyses of AmI that is the creation of a processable and implementable physical basis for ambient assisted life technologies and applications. The physicality of ambient intelligence is a ‘killer application’ that will also drive sustainable printable consumer electronics and will be a significant factor in the uptake of nanotechnology [3]. What is the best way to use ambient intelligence and in what ways can it enhance the way we live? On starting to scrutinise the current facts it quickly becomes apparent that this is an interesting and exciting challenge. To examine what is intended by ambient intelligence and what will be its potential consequences is important contribution to the development of a calmer society, to more satisfied consumers and accelerating a printed electronics future.

2 Disruptive Technologies and the Emergence of AmI Environments

A common barrier to sustaining a high rate of growth in any industry is the existence of fundamental limitation to the basic technologies on which the industry depends. Improvements are instead evolutionary in nature and focussed largely around operating cost reduction. However, by contrast, no fundamental limitation in the technologies enabling the semi-conductor industry has yet arisen as a significant barrier to its continued growth. Beyond 2016 and the demise of the ‘top-down’ lithographic technologies employed, ‘bottom-up’ nanomaterials fabrication for nano-electronics have the potential to move electronic materials, computers and devices into a new era of sustainable growth. There are still so many opportunities for further improvements in electronics technology, the question of whether it will continue to enjoy rapid growth depends on a different consideration – will the potential new applications that can be supported by increasingly capable electronics technology fulfil a societal need? Will there be a new application area, like the PC or mobile phone to restore high growth to the industry? Ambient Intelligence is the most obvious candidate. It has the potential to fulfil a significant societal need – the need to simplify human interactions with the plethora of electronic devices that surround us today and take advantage of the unfulfilled capabilities of electronic devices to make life easier and more productive through ubiquitous access to information and knowledge. If this technology is widely accepted and adapted, it will certainly establish rapid and sustainable growth in the electronics industry. The concept likely to gain a significant degree of acceptance of this technology is its potential to improve the quality of our lives. Figure 1.

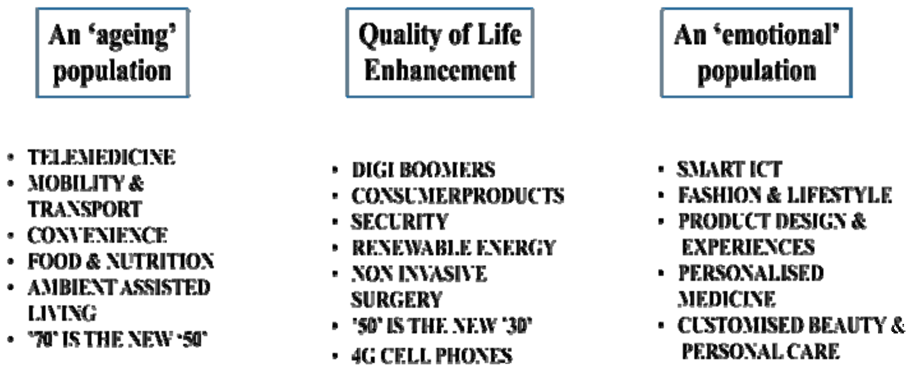

Fig. 1. Putting the citizen at the centre of technology

3 Ambient Intelligence Origins

As a key element of the physical AmI concept, the computers recede into the background. AmI at its most effective will engage only the periphery of our attention and engage the centre of our attention only when the 'visible invisibility' situation demands it. A 'calm technology' will enhance our peripheral reach by bringing more details into the perception, making us feel at home in a comfortable space. Model systems examples include the automobile, the airplane and the built environment. By contrast, the current generation of PC's and other personal electronic devices are not 'calm' but at the centre of our attention when we interact with them [4].

3.1 Ambient Intelligence Development

AmI, emerging in the 1990's, presents a vision for 'soft' electronic technologies from 2010 onwards. Lighting, sound vision, domestic appliances personal healthcare devices, furniture, interior walls / surfaces and distributed services all cooperate seamlessly with one another to improve the total use experience through the support of natural and intuitive interfaces. Ambient intelligence builds on mobile and pervasive computing and refers to electronic systems that are sensitive and responsive to the presence of people. 'Ambient' here refers to the need for a large scale embedding of technology; 'intelligence' refers to the digital surroundings exhibiting specific forms of social interaction. By implication, embedding through miniaturisation and novel direct write techniques is the systems design objective from a hardware point of view. For software, the main objective is to introduce true intelligence into the systems [1], [4]. One of the most significant conclusions from the field of embedded technology is that the design and manufacture of electronic devices has indeed reached a level of miniaturisation, transparency and conformability allowing integration of electronic systems (organic CMOS) for processing, communicating, storage display and access into any possible physical object, like clothes, furniture, cars and homes – thus making peoples environments 'smart'. This

this recent discovery, described below, will accelerate and enhance the ubiquitous take-up of AmI and is the basis for driving many aspects of plastic electronic applications.

3.2 System + Social + Cognitive Intelligence

The AmI vision has human needs as the key element in the development of digital innovations, while technology is seen as a means to achieve this objective. Aspects such as information overload, violations of privacy and a lack of control and trustworthiness in general, threaten the introduction of novel technologies into our everyday lives and consequently, it is often not clear whether people will perceive such scenarios as beneficial. Essential are the user experiences perceived when interacting with AmI environments. Examples of such experiences are immersion in social connectivity, viewed as emergent features of intelligent behaviour in AmI systems. The system intelligence drivers i.e. context awareness, personalisation, adaptive behaviour and anticipation, primarily facilitate intelligent communication with AmI environments, thus providing users with a means for intelligent interaction and control. With the increased expectations of AmI technologies, the true intelligence of AmI environments requires complying with societal conventions and with cognitive intelligence, allowing for sensory and emotional experiences and judgements [6], [7].

3.3 Materials Intelligence and the Rise of Electro and Photo Active Conductive Polymers

To meet many of the above criteria, materials and devices are needed that are physically unobtrusive, embedded in the common environments of the everyday. The crucial breakthrough in materials came in the 1980's and can now drive AmI forward. These materials are known as OFEDs – organic, flexible electronic devices. OFEDs are derived from a molecular engineering approach to create an intelligent materials platform. Solution processed OFEDs are attractive and it is now possible to envision a high throughput reel to reel (R2R) printing process to make large area OFEDs at low cost. Possible techniques for high throughput large area printing are screen, gravure or flexography The heart of the design paradigm for solution processable OFEDs technology lies in adding as much functionality as possible into the active organic materials and then use these materials in device structures with as few active layers as possible. Scaling solution processable technology for large area OFEDs requires the development of new solution based processes. To do this systematically requires a deep knowledge of the behaviour and characteristics of both polymeric and small molecule organic semiconductors. Over the last three years, such materials driven technology has reached demonstrable scales of operation compatible with realistic testing for ambient intelligent applications [8]. The reason for these developments is the fact that many of the new functional materials are solution processable. As mentioned previously, the classes of material which are becoming available are derivatives of the original discoveries made by Heeger et al [10] in the late 70's based on conjugated, conductive polymers and by Friend et al [11] in the early 1980's based on light emitting polymers - in other words, conformable, lightweight, transparent electro and photo active polymeric and to a lesser extent, small molecule organic materials. When we couple these to:

a) creative design principles and techniques and
b) assistive human benefits through medicine, transport, shelter, information, communication

then we create both a needs driven and market driven set of drivers, accelerating the implementation of processes to make AmI environments at the most economical cost, while providing valuable functionality and/or experiences [9]. A major benefit, which impacts the uptake of OFEDs, is the fact that many of the 'active' materials can be synthesised in the form of polymeric and gel solutions. This flexibility, in a phase transformation such as a chemical reaction, a cross linkage step, a solidification, a drying or a curing step, allow the transition of bulk fluid to controllable physical forms [12] i.e.

a) Droplet and spray production ('dots')
b) Fibre spinning & material phase transformation ('lines')
c) Thin film, multilayer extrusion & deposition ('surfaces')
d) Rapid Prototyping - 3^D printing & injection moulding ('structures')

These methodologies allow designers much greater flexibility to create the desired 2D & 3 D materials and to experiment with multiple composite forms previously untried, if given ample quantities of material [13].

e) 'Dots': planar, sheet to sheet printing, using DoD ink jet for small & large area applications (cm^2)
f) 'Lines': fibres (weaving, knitting, sewing & embroidery) for relatively large area applications ($m^{2)}$
g) 'Surfaces': large area screen printing, Reel To Reel web based printing and multilayer, thin film extrusion for very large area applications (km^2)!

On Body Applications

a) Clothes & Fashion: light, sound, sensory effects in location/mood context
b) Healthcare: point of care diagnostics based on bio sensors in clothing. Patient care – chronic wound monitoring, therapeutic response and data reading & analysis
c) Personal/Beauty care: controlled release materials with smart environmental triggers for sensory, body temperature and antibacterial benefit.

Around Body Applications

a) Transportation: Organic pixelated lighting, controlled by the driver's and passenger's state of tiredness, need for information etc. Bio sensing of both people and environment integrated into sensory responsive hydrogels

b) Built environment: Smart furniture, interior walls, carpets and curtains, draperies, provide information on an individual basis, using RFID / Bluetooth signalling and large area ultralow cost sensor driveways. Smart health sensing, for both the inhabitants and the fabric, of the living space
c) Renewable energy: Large area portable (power) storage and hence low cost heating and lighting into off grid living environments

4 New Research Perspectives

AmI development and implementation is relatively still in its infancy. As with most disruptive concepts, this is primarily due to the gap that exists between the fiction of the conceptual vision on the one hand and the intricacy of the realisation on the other. The factors which influence the speed of uptake can be distinguished as follows [14], [15]:

4.1 Ambient Control (AmC)

To access and control devices in an AmI environment, the issue is integrating the physical world into the digital world with functionalities like sensing, actuation, identification and secure (wireless) access, collecting and interpreting information about objects and their surroundings. It should support context, meaning, sensory effects and semantics. AmI should also support the distribution of media over physical devices, to integrate virtual and physical worlds and enable the distribution of media onto physical objects, supporting combinations of the senses: audio, video, lighting, fragrance and vibration through to distributed media services. This is what Aarts calls the extension of 'Quality of Service' (QoS) into the concept of 'Quality of Experience' (QoE) [6]. To provide ambient control, a standardised open platform is needed. A promising approach could well be the 'internet of things', a novel use of the current internet, aiming at serving and activation through URLs and quality controlled access layers i.e. access to physical layers, surfaces and interfaces. The interactive nature of these surfaces and interfaces can now be realised with active fabrics and non-woven thin films that can be designed and incorporated into many everyday objects.

4.2 Sensory Experiences

To process information in the interaction with AmI environments, the issue is to understand the interaction between the human brain and its environment. This field is concerned with the investigation of fundamental and essential functions of the brain, including perception, thinking, emotion, learning, memory, attention, heuristic search, reasoning, discovery, creativity and surprise [7], Figure 2.

Key elements are the measurement of the emotional and mental state of the users in a reliable way and using this information to enhance the interaction with AmI environments. Capturing, influencing and generating emotions is a new field of research and is often referred to as 'affective' computing. Key questions include:

how can we model a mood state? Which moods do we need to be able to capture? How does triggering a set of senses influence the perceived emotions? Sensing and actuation of sensorial effects in relation to human activity are important elements in the development of effective solutions in sensory experiences [16].

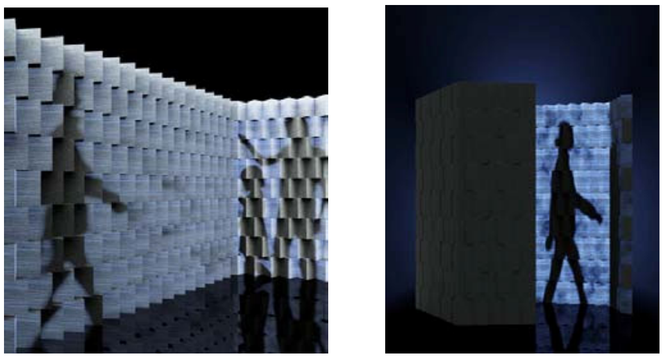

Fig. 2. Looking through a concrete wall, light transmitting concrete blocks embedded with luminous glass fibres. ©Litracon

4.3 New e-Inclusion

What does it take for people to accept that their environment is monitoring their every move, waiting for the right moment to take over the purpose of taking care of them? Much of the acceptance will depend on the perceived functional benefit of AmI environments and on the availability of mechanisms that enable participants to make their own choices in a way that is understandable, transparent and independent of their comprehension level.

4.4 Ethical Concerns

Personalisation requires registration and recording of the user behaviour. The explicit knowledge about the so-called 'digital soul' of human beings requires the development of different standards for social behaviour and it might even be desired to protect people against their own attitudes. Ethical concern is given to the possibility to incorporate AmI into the human body. We are already incorporating intelligence into our clothing and we are happy to have a pacemaker built in. Targeted drug delivery or minimally invasive surgery approaches are medical treatments based on embedded electronics; evidently, this has a medical justification.

5 Northumbria University School of Design / Royal College of Art Activities

Over the last two years we have been examining the interactive factors that are required to create and interpret aspects of human centred needs that constitute ambient assistive technology of sustainable value. In addition to those factors which have been well documented in the literature, i.e. system and social intelligence [2], we can only move towards a robust physical basis for AmI if we have at our disposal new, innovative materials with appropriate molecular and electronic structures. Conjugated, conductive polymers integrated with nanoscalar materials yield a sound

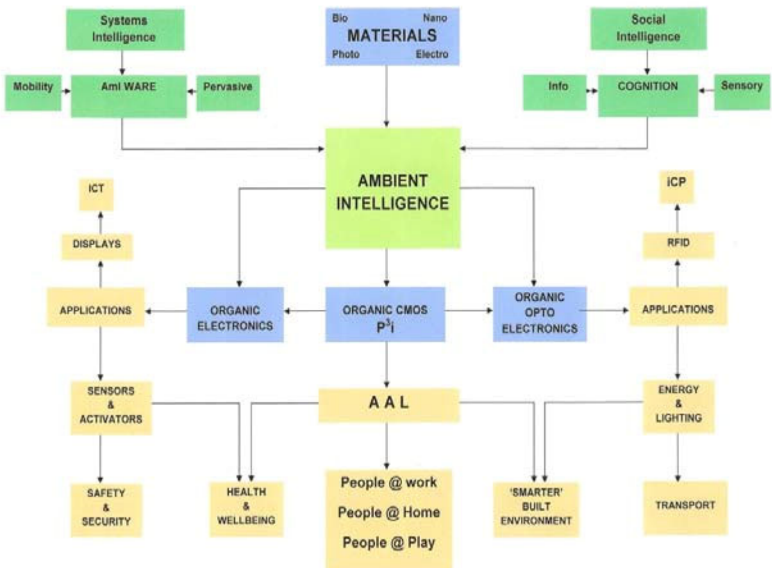

Fig. 3. Northumbria / RCA template to advance the Design – AmI interface

platform for the physicality of AmI and hence beneficial applications in ambient assisted living. Figure 3 above details the mapping process we are using to plot a path towards physical AmI based on electro, photo and even bio active and responsive polymers and gels. A crucial element is the solution processability of these materials that allows deposition and/or embedding into almost any surface shape [17]. The future goal of the work is to develop'Active' Materials for Life design research hub, to explore the deployment of physical AmI through needs driven applications in assistive health, transport, the built environment and interactive consumer products [18].

5.1 Design: STEM Explorations in Physical Ambient Intelligence Environments

Much has been written on the development of HCI and 'smart' environments. All are based on the use of Silicon semiconductor technology to provide programmable environments. The recent growth and interest in organic conductive polymers mentioned earlier allows further advances to be made on three fronts:

a) Solution processable, transparent conductive polymers which are printable, paintable and programmable, i.e. organic CMOS
b) Such materials are transparent, lightweight and conformable and are thus capable of creative design development
c) Beyond the ability to code electro and photoactive conjugated conductive polymers and stimuli responsive gels, biopolymers and shape memory alloys yield substantially greater bandwidth in terms of physical and emotional actions.

5.2 An 'Active' Materials for Living Platform [AMfL]

As examples, we are investigating aspects of a), b) and c) in a joint interactive design research studio P^{3}i (paintable, printable, programmable materials) environment with contributions from textiles and fashion design, industrial design, materials chemistry, systems biology, chemical nanotechnology and printed electronics based hardware design. This skill set forms the basis for the P^{3}i interdisciplinary design research centre at NUSDL and is focussed on an 'Active Materials for Living' platform with the work programme pillars: SENE, BIOSYS, AMBIENT and KNIT.

SENSE: Smart, Sustainable Multisensory Material Design. This pillar focuses on mental wellness and sleep disorder by delivering effective new ways to improve emotional wellbeing.Fusing design-led wearable technologies that sense the human condition with aromachology research, new product focus can be generated which dispense as 'casket' of fragrances to influence moods or emotional states in different situations. The programme of design research includes the development of wearable technology and responsive jewellery as convenient delivery vehicles for fragrance 'bubbles'.

BIOSYS. Biosys is an explanation of the benefits which can be achieved through the convergence of biology-polymers-electronics and the use of printed systems technology to create a bridge between sensing, bio mimicry and responsive materials, in particular, the creation of bio-textiles as wearable technology with suitable properties activated by chemical sensing and actuation. Another focus is on sustainable bio fibre and fabric production through novel biological processes; applications for bio responsive and bio compatible fabrics lie in transportation and architecture as well as in sustainable textiles for fashion.

The above two pillars relate to systems biology, printable sensing and novel product fabrication technologies towards organic ambient environments.

AMBIENT & KNIT. Both of these projects focus on the emergence of organic CMOS to provide a physical basis for Ambient Intelligence (AmI) through conformable and often transparent active materials integrated with printable sensing. The focus is on science & design in society, embedding intelligence into social environments in three areas of life quality:

a) Assets in Life (home, the car, furniture, interiors, clothes)
b) Phases in Life (childhood, youth, parenthood, old age)
c) Aspects of Life (learning, sleeping, eating, connecting, networking)

The materials and technologies to create ‘visible invisibility’ are being examined through specific ways of creating AmI in either everyday objects or through some of the wearable technologies.

6 Conclusions and Final Remarks

Substantial technological and societal barriers to the full implementation of AmI are described by Weisser [1] and by Aarts [6]. They even push implementation into the distant future, but partial implementation, designed to make life easier and improve the effectiveness of work processes without threatening privacy and freedom of action, is likely. Another partial implementation route is centred on RFID where the possible applications include full implementation of AmI. Applications relating to retail, security, transportation, manufacturing and shipping are users of RFID tags produced in high volumes at very low cost and are a significant user of plastic electronics capability today. In the full integration of physical AmI, wearable electronics or ‘smart’ textiles on clothing are an important element in ambient intelligence computing, communication and I/O interface implementation. Conversely, in the absence of success with AmI it is doubtful that wearable electronics will result in anything beyond novelty items. However, novelty should never be underestimated as an early driver for the uptake of new products. In addition to novelty, the needs of the military and security sectors and of haute couture are significant drivers for wearable electronics, wearable light and also wearable (and disposable) power and is well illustrated by the work of Suzanne Kuechler (at UCL) works on materials culture & communication to enhance aesthetics & functionality [19]. If implementation is done well, all of these elements will work together as a calm technology, reducing the current clutter of activities that we expect as part of the work environment [20]. It is not likely that ambient intelligence implementations would be just as visualized by Weisser. This emanates from the proven inability of anyone, however brilliant, to predict the future of technology. It will not be a surprise if ambient intelligence is highly successful, but the eventual implementation will certainly be different in important ways from that presently visualised. The basis for physical AmI is now available through the use of electro, photo and bioactive polymers and gels, which are solution processable. To ensure a reasonable and sustainable uptake of AmI to improve the quality of peoples' lives, a number of key materials and tools need to be in place:

a) Innovative display fabrication
b) Useful opto electronics
c) Miniaturised micro and nano printed sensors and actuators
d) Integrating much of the above into a creative design platform

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