Miniaturised Modular Wireless Sensor Networks.

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ABSTRACT

This paper focuses on the development of miniaturised modular wireless sensor networks that can be used to realise distributed autonomous sensors for future ad-hoc networks in the ambient systems and intelligent environments arena. Such modular, mobile networks are key enabling technologies in the field of ubiquitous computing.

The modules are fabricated in a 3-D stackable form with a novel modular PCB design which can be mounted on artefacts or on parts of the body, can measure acceleration, rotation, shock, elevation etc. and have a low-power RF channel-shared link to a base station (for sports, exercise, entertainment, health). The modular nature of the design allows for extra panels to be developed and added easily.

Keywords

Modularity, wireless sensor networks, 3-D packaging.

INTRODUCTION

Major research efforts are currently targeting the "disappearance" of the computer into the fabric of our environment. In the future, the spaces we live in will be populated by many thousands of objects (often described as "artefacts") with the ability to sense and actuate in their environment, to perform localised computation, and to communicate, even collaborate with each other. Artefacts are playing a large role in research towards intelligent systems and ubiquitous computing. There are two prime drivers: the smaller these objects are the more effective they will be in providing opportunities for integrating the physical and digital worlds, and the greater the number of objects within these systems/networks the more valuable the networks are. The main properties required to maximise the capabilities of such networks are that it should have, granularity (i.e. high resolution), reconfigurability modularisation and mobility. The system level implementation will be realised through concurrent hardware and software engineering; innovation in software should be matched by invention in hardware. It is important that novel hardware technology platforms are used for object and system development, incorporating 3-D stacking, mu lti-chip and micro-sensor integration, thin and flexible substrates, active polymeric materials, smart materials, and ultimately micro-nano-systems. To do this, new form factors for hardware need to be investigated, optimizing performance. In this light, the key initial considerations are interconnection and modularity of the hardware.

PROBLEM STATEMENT

Recent developments in wireless and micro-sensor [1,2] technologies have provided foundation platforms for considering the development of effective modular systems (see figure 1). They offer the prospect of flexibility in use, and network scalability. Currently, most sensor networks are strongly integrated into the assembly process of their target systems (E.g. the automobile, production line equipment, aircraft, etc). Thus, they carry a high infrastructural overhead. Emerging autonomous formats include wireless units designed to collect data and transmit to central (or distributed) hosts. Interesting examples include passive/active tags, inertial measurement units (IMU), the 1cm^2 wireless integrated micro-sensors at UCLA [3], and the "Smart Dust" project [4,5] at the University of Berkeley.

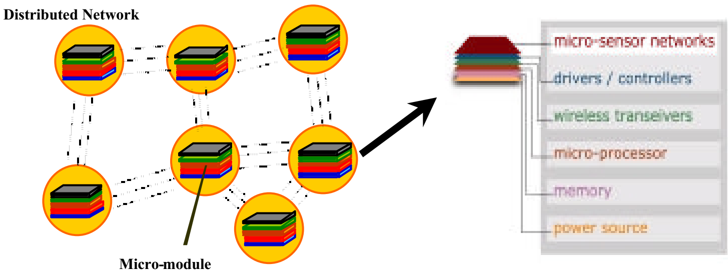


Figure 1: System Format with Modular Nodes.

The availability of modular systems will provide a valuable research tool for ambient systems and ubiquitous computing. Thus, a modular approach initially for a wearable sensor network, including functionality as an inertial measurement unit has been adopted by the NMRC. The module comprises an ensemble of 16 sensors, electronic interfaces, and a wireless transmitter manufactured using a combination of current surface mount techniques and multichip packaging (MCP). The sensors included accelerometers, gyroscope, compass, pressure sensors, bend sensors, electric field sensor and sonar pinger The module includes; an integrated PIC micro-controller with A/D converter, separate 256K EEPROM memory for local data storage and a 433MHz RF Transceiver with 20kbit/s data rate within a multi-chip module (MCM). Current prototypes consist of miniature sensor packages that can be worn on limbs and torso or mounted within artefacts.

BACKGROUND

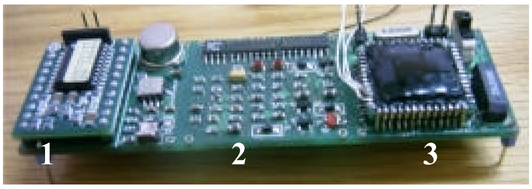
The miniaturised wireless sensor networks presented here are the evolution of a project collaboration between NMRC and MIT Media Lab with the aim of miniaturisation and ruggedisation of the MIT Media Lab "expressive footwear"[6]. Prof. Joe Paradiso and his team at the MIT Media Lab have prototyped a sensor component network of 16 sensors that are integrated with a wireless transmitter and mounted onto a shoe (expressive footwear) [7,8]. The sensors were located either in the insole or on a PCB attached to the shoe. A dancer, equipped with a pair of this footwear, has every movement monitored by an off-stage computer. Although currently used to explore applications in interactive dance, this system also has applications in areas like sports training and medicine, interactive exercise, and podiatry diagnosis and therapy.

MODULE EVOLUTION

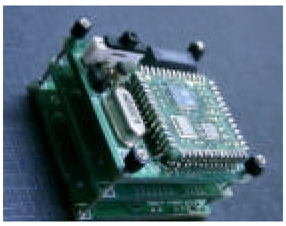
The re-design of the module took place in 2 phases: the development and ruggedisation of the wearable sensor platform and the re-design of the circuits for the miniaturised modularised form factor.

The ruggedisation was necessary to improve the module reliability. This was done in two steps. Firstly, the wearable sensor portion of the circuit was re-designed and fabricated on Copper-clad flex. Sensors incorporated in the flex circuit included bend sensors, dynamic pressure sensors and force sensing resistors. Secondly, these circuits were laminated between protective plastic sheets and reliability tested through a series of non-standard reliability tests with a high yield.

During the design phase of the module, a building block technique for the autonomous wireless sensor network was developed. The formal re-design of the module PCB was completed with the aim of miniaturising and modularising the circuit to allow it to be unobtrusively worn anywhere on the body. The final design was realised as a 90mm x 30 mm two layer PCB which could be mounted as is or separated into three 30mm x 30mm panels which can be positioned on any portion of the body. Figure 2(a) shows the module before segmentation while 2(b) shows a separated module.



(a)



(b)

Figure 2: Autonomous Sensor Network Node with Modular Design Format (a) before, and (b) after segmentation.

The 3 panels visible are 1) the inertial measurement panel 2) the force sensors interface panel and 3) the wireless transceiver panel. The modular format of the PCB allows for extra panels to be designed and manufactured as and when required. Though stacked in 3-D in Figure 2(b), miniature flex cable connectors on each panel allow the modules to be connected in a variety of different ways and in an unobtrusive manner. Preliminary versions of this module have been utilised in projects including a wearable network, interactive glove and a localisation system.

CONCLUSION AND FUTURE WORK

This paper has presented the work done in evolving a module for a miniaturised wireless sensor network. The implementation of this form factor is useful in numerous applications, including for sports, exercise, entertainment, and health; in addition, the imaginative use of flex circuitry may provide for further form factors to be evaluated (for example, connected panels could be wrapped around the wrist). The current size is too large to expand the application potential of the form beyond niche level; the realistic number of stackable panels is currently four. To expand the viability of the format, it is appropriate to look at the potential for further miniaturisation of this module with an initial target volume of 1 cm^3.

The continuation of the project will focus on challenges, which are key to bringing the intelligent environments concept to reality: 1) The further development of high density, (3-dimensional) packaging technology platforms to enable increased miniaturisation of micro-sensor modules incorporating application-specific sensors, data acquisition, signal processing and wireless communication 2) Applications in a mobile/wearable domain with emphasis on context, and design 3) The realisation of a distributed system of micro-sensor modules. There will be an increased focus upon design and development of appropriate form factors for mobile/wearable applications and realisation of the target dimensions.

ACKNOWLEDGEMENTS

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