Pin&Play: The Surface as Network Medium

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ABSTRACT

Integrating appliances in the home through a wired network often proves to be impractical: routing cables is usually difficult, changing the network structure afterward even more so, and portable devices can only be connected at fixed connection points. Wireless networks aren't the answer either: batteries have to be regularly replaced or changed, and what they add to the device's size and weight might be disproportionate for smaller appliances. In Pin&Play, we explore a design space in between typical wired and wireless networks, investigating the use of surfaces to network objects that are attached to it. This article gives an overview of the network model, and describes functioning prototypes that were built as a proof of concept.

INTRODUCTION

The most common home appliances (e.g., refrigerators, TV sets, hi-fi systems, game consoles) are relatively large in size and usually remain in the same spot for long periods. It is therefore obvious and worthwhile to provide a wall socket that gives them power and networking. However, a lot of appliances we use in our daily lives are used in different rooms and corners of the home. Many of these are furthermore small in size, and their form-factor makes it difficult to plug them into a wall socket, or to supply them with a cable and connector. Cradles or docking stations provide a means of networking devices like mobile phones, personal digital assistants (PDAs), digital cameras, or laptop computers, but these are different for each device and are not usually omnipresent in the home.

Although wireless networking is becoming more popular in the home, it still lacks some essential features. Wireless transmission first of all costs energy, which means that batteries are required that need to be recharged or replaced at certain intervals. This "feeding" routine also becomes more tedious as the number of wireless devices increases. A second problem is transparency: it is no longer obvious what is networked and why; a natural structure of the wireless network is lacking. This could be the source of various problems, especially in relation to privacy and security issues.

Work in home networks includes provision of consumer electronics (e.g., IEEE 1394, "Firewire"), the use of existing infrastructure (e.g., power line and phone line), and the deployment of wireless solutions (e.g., 802.11, PAN, and Bluetooth). The objective of this article is not to directly challenge any of these developments, but instead to propose a complementary technology, addressing a networking design space between wired and wireless technologies.

The approach exploits the fact that many objects remain immobile for most of the time, i.e. they rest on a table surface, or hang from the wall. These supporting surfaces become in our concept the source of both network and power, for all network enabled objects on that surface.

If we take the wall as an example of such a surface, then the networked objects could be devices we are already familiar with, such as wall-mounted clocks, wall switches, wall lights, posters, thermostats, or pushpins. Or they could be completely new objects. A visual characteristic of these objects is that they have a pin connector. The fastening to the wall not only provides placement and physical support, but additionally power and network connection. Introducing these devices to a power and networking source is therefore as straightforward as pinning them to a wall; hence, the project's name: Pin&Play.

SURFACES AS A NETWORK

We start with introducing the general idea of surfaces as a medium for the objects touching it, which is more general than the Pin&Play vision. There is a broad spectrum of research that in a wider sense is related to ours, such as research into ubiquitous computing networks, on interactions in smart environments, and also on how people interact with physical space. We will briefly discuss research that is particularly close to ours in the networking sense.

Lifton and Paradiso have proposed Pushpin Computing [1]. They use a surface with pushpins and layered conductive sheets, where direct contact to the conductive layers in the board is used

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to obtain power. Networking is established locally via infrared or capacitive coupling, with neighboring pushpins in a close (~10 cm) range. In this concept, pushpins feature as explicit computational elements to create a new type of architecture, based on a huge collection of computing elements. The pins are required to be close to each other, and the network routing needs to be completely handled in a distributed fashion, which increases the complexity a great deal for use as a network in home environments.

The Networked Surface at Cambridge University [2] focuses on horizontal surfaces such as desks and tables. In contrast to Pin&Play, the created network is primarily aimed at connection of higher-end computational devices that are placed on top of it, such as handhelds and laptop computers. Instead of using layers, the Networked Surface is composed of cleverly placed tiles, such that there are connections to power and communication channels at all times. Objects can be connected to the surface through circular pads designed to map with connection points onto the tiles. These pads are considerably larger than Pin&Play connectors, which makes this approach less obvious for very small objects. Interesting, however, is that the Networked Surface also provides information about position and orientation of objects, to be derived from the internal surface structure. A drawback of this structure is the complexity: the network has to manage a large number of tiles in the surface and negotiate connection points with object adaptors.

Architecture

Pin&Play is based on the vision that walls and other surfaces can be used as a bus network for objects that become attached to them. This is a vision that requires a novel network composition, and is concerned with qualities not typically considered in networking, such as facilitation of networking devices in the home environment and exploitation of affordability for ease of use.

Components

Pin&Play has four main components:
- Surface: physical medium for both data and power
- Connector: physical device for attachment of objects to the medium
- Objects: network nodes powered and connected through the surface
- Network: network control and communication protocols

Surface — The purpose of the Pin&Play physical network medium is to provide both network connectivity and power to attached devices. Instead of wires, it uses conductive sheets, as the objective is to facilitate entire surfaces as two-dimensional networks. As solid sheets would leave holes when pin-shaped connectors are inserted and later removed, woven fiber sheets [3] are used instead. Pin&Play surfaces are composed of multiple layers of such sheets embedded in common surfaces. An anticipated challenge with the use of sheets rather than wires is that the resistance and especially capacitance can be expected to hinder communication. However, a range of conductive materials are available that are optimized for low resistance. In general, the surface design is aimed at simplicity and low cost (e.g., avoiding subdivision into tiles) to support our vision of deployment in everyday environments such as the home. Deployment of the surface material could, for instance, be envisioned in the form of smart lining under standard wallpaper in the home, to enable entire walls to act as a shared medium for objects that are attached to them.

Connectors — The design of Pin&Play connectors is aimed to support two very different functionalities in a single mechanism. First, they obviously have to support physical connection of Pin&Play network nodes to the surfaces (they would be the plugs if the network were not socketless). Second, they should support attachment of objects based on existing and familiar practices. The connector design is therefore based on pushpins that can be stuck into Surfaces, and that can be removed as easily, thus employing a truly ubiquitous device that is commonplace in home and work environments. The connector design is further aimed at flexible augmentation of objects and hence conceived as an adapter rather than a built-in physical interface.

Pin&Play Objects — The very idea of Pin&Play is to provide networking to objects that are commonly attached to surfaces, rather than to conventional computing devices. In general, we consider two different types of object. First, we envision that any kind of object that people would attach to vertical surfaces can be "upgraded" to a networked object while also retaining its original appearance, purpose, and use. This would apply, for example, to picture frames, artwork, wall calendars, clocks, light controls, and so on. Second, we envision objects that succeed today's mundane and ubiquitous connectors and fasteners, for example, "Smart Pushpins" that can be used to attach notes to boards but in addition provide new functionality on the basis of being digital and networked. Obviously, both types of objects require unobtrusive embedding of computation and network interface. In this context it has to be noted that Pin&Play objects do not require their own power supply unless they are required to be on in detached mode.

Pin&Play Network — Objects become powered up when they are attached to a surface. It is the task of the network to discover newly attached objects and to maintain network state. The network furthermore has to provide the communication protocols for the connected nodes. A primary optimization target for the network is to support large-scale surfaces, high density of nodes, and ad hoc integration of previously unknown objects, while bandwidth is of lesser concern.

Properties of the Pin&Play Concept

The design of Pin&Play differs substantially from other conventional computer networks and other networks proposed specifically for ubiquitous computing.

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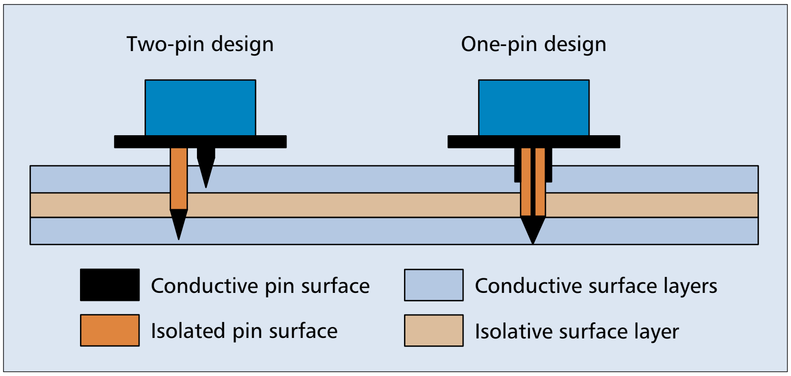
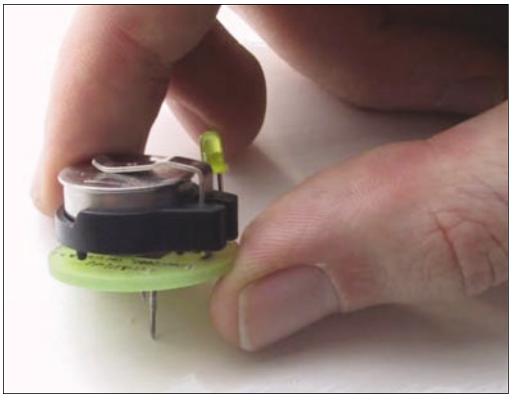


■ **Figure 1.** *A diagram of the pin connectors that access the right communication line of the bus network.*

Networking Properties — Pin&Play addresses a design space between wired and wireless technologies. On an imaginary scale of ubiquity of network access, it goes beyond one-dimensional wired structures in providing network access across 2D surfaces, while of course not going as far as offering connection throughout 3D volumes. However, we consider it likely that overall higher density of nodes per room can be achieved if the enclosing walls were networked, in comparison to the state of the art in wireless technologies. A main advantage of Pin&Play over wireless technologies is that it provides power to connected objects, and thus supports the integration of objects that have no batteries or other forms of power supply. The approach is very similar to that of a PDA cradle or a laptop docking station, but with minimal constraints concerning where and how to connect the object, and with more direct interconnection possibilities.

Use-Related Properties — We already stressed that the Pin&Play concept is firmly built on common structures. It addresses important user values such as familiarity of the concepts used, better observability of network configuration, and straightforward control in the sense of minimal-effort attachment and detachment of objects. Pushpin-like connectors provide strong affordability, and the user act of connecting an object to the network becomes embedded in the act of attaching it to the wall or other surface. Another important property is the free placement of objects on a Pin&Play surface. People use surfaces for meaningful spatial arrangement of objects, so it is valuable that surface augmentation does not constrain such use.



■ **Figure 2.** *A close-up of an assembled pin. The current model has two isolated pins for accessing the top and bottom layers. The one-wire switch is hidden below the i-Button's connector, next to the LED.*

Deployment Vision — Pin&Play's design is clearly targeted at real deployment in everyday environments, such as the home. The components underlying Pin&Play, in particular layered conductive fiber sheets and pin-like connectors, require careful mechanical design but do not involve sophisticated or expensive technology. If a satisfactory design is achieved, production at low cost would certainly be realistic.

Networked Notice Board Pins

To illustrate the kind of application in which the Pin&Play concept becomes superior to the typical wired and wireless approaches, we start with an application using extremely small and densely networked devices. This section introduces a smart version of the common pin that is enhanced with processing capabilities and memory, to store information about the document it attaches to a notice board. We will first describe the implementation of each Pin&Play component as introduced in the previous section.

The Surface: Notice Board — The surface is here embodied by a notice board, physically augmented to a network bus by adding two conductive layers to an insulating layer (for which both corkboard and adhesive rubber sheets were used). The conductive fiber sheets [4], which are traditionally manufactured for shielding applications, are not only straightforward to apply; they also leave no holes once the pins have been removed, which ensures longer usability than solid conductive sheets. The fabric is usually silver (Ag) or nickel-copper (Ni-Cu) plated nylon that has been woven and has a typical thickness of 0.1 mm (0.005 in). The conductivity, furthermore, is extremely low (i.e., below 0.5 Ω/□).

The Network — To facilitate implementation of the network protocol, the Dallas MicroLAN [1] was chosen as the base communication layer, as it is an inexpensive and flexible networking standard. It only requires two wires (one provides a bus for data transmission, plus a ground reference), but also allows network nodes to steal power from the data line. A large variety of network components that communicate via MicroLAN is available and range in application from simple identification devices and read/write memories to sensors, data loggers, and switches.

MicroLAN makes it perfectly possible to build huge networks with many components that can be dynamically added or removed, supports interrupting, and requires a pull-up voltage between 2.8 and 6 V. This scalability and flexibility comes at a price, though: the maximum communication bandwidth is at best 16,300 b/s, limiting the type of network application running on the bus. The structure of the MicroLAN is

■ **Figure 3.** *A working example of the networked notice board application. All pins are connected to the network bus, and generate an interrupt as soon as they meet their expiration date and time. They are powered by the notice board as well.*

furthermore typically a master-slave architecture, where the master could be connected to the surface as just another pin, accessing both layers to provide the essential power and communication to the board.

The network bus master in this application was a common PC, connected to the notice board with a MicroLAN-to-serial adaptor to control the network. This task is simple enough to be done by a microcontroller, though, which could be integrated in the board in future applications that go beyond prototyping.

The Connectors — Our current prototype has two isolated pins to get into the front and back layer of the corkboard, much like that of the Pushpin Computing approach [1]. This connector design, with the larger pin partly covered with a transparent insulator, has the disadvantage of being fixed in orientation once it has been plugged in, and being more vulnerable to shortcircuits since the tips of both pins are more accessible (Fig. 1).

Additionally, the two-pin configuration is slightly harder to plug in, and alienates the Pin&Play pin somehow from traditional pins. It does, however, already illustrate the ease of pinning an object into the surface to provide it with power and networking capabilities. As an alternative, we also consider a single-pin design, where the short pin is replaced by an insulated cylinder around the longer pin (Fig. 1).

The Objects: Smart Pins — After having discussed the connectors, the surface, and a bus protocol, we now move on to the actual objects. The smart pins need to be extremely small (compared to common networked devices) to remain usable and familiar to users.

Figure 2 shows our current prototype pin, which has at its heart a Time-in-a-Can iButton [5]. It is a self-sufficient component, containing its own battery (3 V Lithium, with more than 10 years data retention!), oscillator (32,768 Hz), memory (4096 bits), internal real-time calendar and clock (precision: 2 min/mo), programmable alarms, and full MicroLAN communications support.

The pushpin furthermore contains a light emitting diode (LED) that can be switched by a one-wire MicroLAN-compatible switch. Connecting a single pushpin hence introduces two MicroLAN-compatible devices into the network that are *just physically* bound in the same package. The Time-in-a-Can component has internal memory, where it has stored its switch's unique address, so both components can be bound together in virtual space as well.

The pin is reasonably cheap and robust: the total sum of required components for one pin is about $US8, using current retail prices, and consists mainly of established off-the-shelf components. Additionally, the rigid structure of the main component (i.e., an iButton, embodied in stainless steel) ensures reliability and a long lifetime despite being a prototype. The tiny dimensions, especially of the Time-in-a-Can iButton (approximately centimeters in diameter, 0.6 cm in height), produce a total size of a Pin&Play pin close to its traditional equivalent.

Many applications can be implemented on this hardware platform. A first function we implemented involved an embedded warning function that highlights documents that have become irrelevant. A form appears on the display next to the notice board whenever a new document is attached to it, on which the user can indicate information about the document. One can store all kinds of meta-information on the pin locally, but an expiration time and date is of special interest since this information can be stored in the pin's alarm functions directly.

When the internal alarm of a pin goes off, it sends an interrupt via the bus system which triggers the network master to activate its LED to indicate that it needs to be removed. This might be a solution to overcrowded notice boards in public spaces where nobody checks the validity of the documents. To avoid confusion, the "importance" of the documents can be used so that only one pin (the one with the highest-priority document) will light up (Fig. 3).

The highlighting of a pin can of course have other purposes: to emphasize documents that become relevant (e.g., to-do items or cinema tickets), or to indicate documents of interest to the user in front of the notice board (e.g., personal messages) (Figs. 4 and 5).

Light Switches and Other Applications

The example of the notice board is just one of many application domains. To illustrate that any wall-mounted object can be augmented in the same fashion as in the previous example, we focused our attention on one of the most com-

To illustrate that any wall-mounted object can be augmented in the same fashion as in the previous example, we focused our attention on one of the most common objects found on a wall: wall switches that control the lights in a room.

■ **Figure 4.** *The necessary data is stored locally in the pins, so they can be moved to a different board. The onboard battery enables the pins to retain their document's data (e.g., when it expires or how important it is).*

■ **Figure 5.** *The computer connected to the board, acting as the bus master, switches the pin's light on and off to attract attention.*

mon objects found on a wall: wall switches that control the lights in a room. Instead of the electrician deciding for the inhabitants where these switches belong, one can use the Pin&Play three-layered surface as wallpaper, and put augmented switches anywhere.

Figure 6 shows the front and internals of a Pin&Play enabled switch. It can report to the network master when the device is being switched on or off, after which the (preprogrammed) appropriate light can be switched. Developing more elaborate appliances such as dimmers or "smarter" switches is very straightforward. Moreover, the network master can be modified to keep logs, automatically activate lights, or monitor light-switching activity in a home.

The user will benefit from the dynamic placement of the switch: if the user desires the wall switch to be located in a different place or orientation, all that is required is pulling it out of the wallpaper and re-attaching it where preferred. Spotlights or wall-mounted lights can be attached and re-attached in the same fashion.

The insulating material used in this implementation is a flexible rubber sheet material with an adhesive side, to make it easier to glue the conductive fabric on. One could imagine this process to be automation-friendly, enabling mass production of flexible layered wallpaper, which can be installed at low cost in both office and home environments.

The components of the surface material are very flexible, which suggests that we don't have to limit the applications to rigid surfaces. A lot of research in wearable computing focuses on embedding circuits in clothing to network several worn devices, which fits seamlessly with the idea of Pin&Play. The clothing could function as the network surface, on which computing elements (sensors, memory, etc.) can be attached in a very ad hoc manner. The fact that decorative pins already exist for clothing makes it more appealing as another possible application.

Conclusions

This article introduces the concepts of the Pin&Play project, which aims at developing a highly integrated bus network in both office and domestic environments. Even tiny devices can be wall-mounted by means of pin adaptors and a surface with layers of conductive sheets, to gain power and networking capabilities with the freedom of being plugged in anyplace or in any orientation.

The use of off-the-shelf components and the MicroLAN network protocol results in robust and small prototypes that are cheap, easy to (re)produce, and yet more than powerful enough for many applications we envision. The network can handle hundreds of devices in a small (but two-dimensional) space, which is especially attractive in the augmentation of small and mobile appliances.

We describe some working prototypes and design choices during the implementation of augmented pins and wall-mounted switches, as an illustration of typical examples for the Pin&Play concept. Future goals of the project will encompass the implementation of more such examples.

Acknowledgments

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References

[1] J. Lifton and J. Paradiso, "Pushpin Computing System Overview: A Platform for Distributed, Embedded, Ubiquitous Sensor Networks," *Proc. Perv. Comp.*, LNCS 2414, Springer Verlag, 2002, pp. 139–51.

[2] F. Scott *et al.*, "Networked Surfaces: A New Concept in Mobile Networking," *Proc. WMCSA 2000*, Monterey, CA, Dec. 2000.
[3] Shieldex Conductive Woven Sheets, Datasheet for Type Tüll," http://www.shieldex.com
[4] "Dallas Reference Manual: The MicroLAN Starter Kit (DS9091K)," Dallas Semiconductors, 2002.
[5] Time-in-a-Can, DS1994 4-Kbit Plus Time Memory iButton datasheet, Dallas Semiconductors, 2002.

ADDITIONAL READING

[1] "Technical Brief: 1-Wire Net Design Guide," Dallas Semiconductors, 2002.
[2] K. Van Laerhoven, A. Schmidt, and H.-W.Gellersen, "Pin&Play: Networking Objects through Pins," *Proc. Ubicomp 2002*, G. Boriello and L. E. Holmquist, Eds., LNCS, vol. 2498, Springer Verlag, Sept. 2002.
[3] M. Weiser and J. S. Brown "Designing Calm Technology," *PowerGrid J.*, vol.1.01, July 1996.

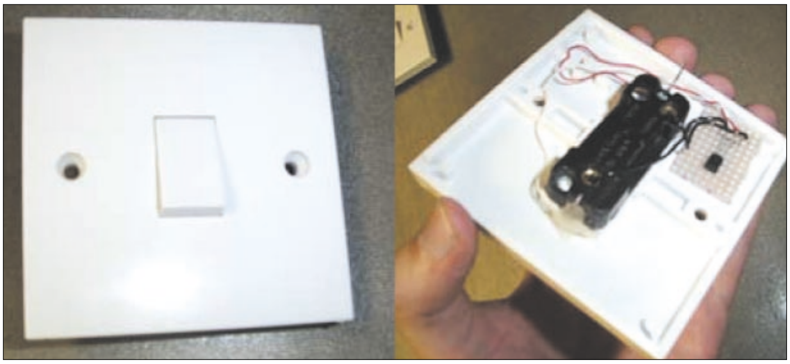

Figure 6. *The front (left) and internals (right) of a Pin&Play wall switch.*

BIOGRAPHIES

KRISTOF VAN LAERHOVEN (kristof@comp.lancs.ac.uk) studied computer science at Limburg University and the University of Brussels (Belgium), where he was mainly involved in artificial neural networks and robotics at the Artificial Intelligence Laboratory. After working at Starlab Research on sensor-based adaptive systems, he moved to Lancaster University, United Kingdom, to work on sensor networks, wearable computing, and machine learning. The subject of his Ph.D. revolves around adaptive recognition algorithms for distributed sensor networks.

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