Interacting with a Speckled World

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ABSTRACT
The vision of truly ubiquitous computing is drawing closer, as show by the work of the Speckled Computing consortium who are developing micro-sensor networks to be invisibly integrated into our surroundings. The unique properties of this technology pose a challenge for current HCI theory, and so we propose a new interaction paradigm based on augmented reality. We report on the principles that form the foundation of this paradigm, and a number of studies that have been undertaken.

Categories and Subject Descriptors
H.5.1 [**Information Interfaces and Presentation**]: Multimedia Information Systems – *Artificial, augmented, and virtual realities*; H.5.2 [**Information Interfaces and Presentation**]: User Interfaces – *Graphical user interface (GUI), Prototyping, Theory and methods.*

General Terms
Design, Experimentation, Human Factors, Theory.

Keywords
Human-Computer Interaction, Augmented Reality, Wireless Sensor Networks, SpeckNet.

1. INTRODUCTION
The Speckled Computing Consortium [11] is a collaboration between five Scottish Universities to develop miniature, wireless sensor network (WSN) devices. The aim is that these devices will be small and cheap enough to be distributed in their thousands; being embedded in building infrastructure, incorporated into objects, or simply loosely scattered around.

These 'Specks' can be invisibly integrated into the environment, monitoring their surroundings and combining wirelessly to form networked sensor meshes, called SpeckNets. These meshes could be formed between objects but also with devices embedded in infrastructure, such as a building's walls and floors. As such people will move within the network, surrounded by it, while also possibly crossing in and out of different meshes.

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The technology and infrastructure in this field as a whole is developing at a substantial rate, but principles of human interaction with them are lagging behind. In this paper we share the foundation for a comprehensive and systematic paradigm for people interacting with, and within, large wireless networks of Specks. It is also expected that many principles can be generalised to other ubiquitous computing systems.

2. APPLICATION DOMAIN
Our focus is on the interaction with a specific type of WSN application, of which we have identified three overlapping classes.

In *Global Overview* applications all of the data (likely from a variety of sensors taken over a prolonged period of time) is required, for example to develop mathematical models of the system being monitored. It is this class that the majority of current WSNs fall into, and information processing can take place remotely utilising the myriad range of information visualisation and data processing techniques that exist.

In *Automatic Response* applications sensor readings trigger a response without user involvement.

Human Intervention applications require a user to perform some task in the environment, based on the sensor net's readings at that point. It is this class that we are most interested in since it is least well covered by current HCI theory, which generally focuses on a person interacting with a processor. In contrast human-SpeckNet interaction is concerned with a person interacting with hundreds or thousands of processors simultaneously. People may wish to interact with the whole network in some circumstance or with just a part of it. Functionality will also change as devices fail, or new devices with different characteristics are introduced.

3. ROLE OF AUGMENTED REALITY
Rehman [11] demonstrated the use of Augmented Reality (AR) to reveal the hidden operation of context triggered applications. We propose expanding the use of AR to visualise the invisible data stored within the SpeckNet.

The proposed AR interface will be implemented on personal mobile computing platforms, focusing on the most common real-virtual blends. These are visual stimuli, where a live video stream can be enhanced with computer generated objects, and auditory stimuli, where computer generated sounds can be supplied to the user's ears so that they appear to originate from locations within the real environment [1]. To a lesser extent vibro-tactile systems may also be appropriate. While the SpeckNet allows computation to be embedded in the environment, the use of Augmented Reality will allow its invisible workings to be brought into the range of human senses. Most importantly the use of augmented reality allows an individual to stand within a SpeckNet and observe information linked to its actual physical location.

There are a number of examples of AR implementations with wearable computing systems, such as Tinmith metro [10]. However they generally do not incorporate real-time data from the environment. A step closer to our vision in the Human Pacman [5] project which includes a number of networked devices, but we are moving towards an entirely networked environment, and taking information from the devices, rather than solely using them as triggers. However, we are not limited to wearable computing systems, since AR had been implemented on a number of platforms including PDAs [14], and next generation mobile phones [9]. We propose to develop a set of software tools which will define the basic requirements for a generic user interface for human-SpeckNet interaction. Our aim is to move beyond designing an interface for a specific system and instead address the most fundamental issues of interacting with a SpeckNet environment.

4. DATA FLOW

Specknets will have a number of differences compared to the WSNs developed to date; superficially in terms of scale, but also due to the proposed system of interaction. While previous WSNs extract data to a database for the user to interact with, in the proposed system the user will be interacting with the environment directly. Hence an individual could be surrounded by a vast store of information without being aware of it.

However there are still a number of relevant WSNs, for example is the vineyard computing [3], where interaction takes place in the same location as the sensors are located. Here a number of sensors are distributed through a vineyard, measuring various properties, which then allow prediction of pests. However, this system limits interaction to a few defined locations, and data is simplified, hiding individual values from human decision making.

A further relevant example is a fire direction system [2], notable because it uses real-world map data to offer a 3D representation of fire distribution. However, it differs both in that this representation is viewed typically remotely on a desktop PC, and in the granularity of the sensor mesh.

By considering the operation of existing WSNs, as well as the unique properties of SpeckNets, led to the formation of a model of dataflow, as show in figure 1.

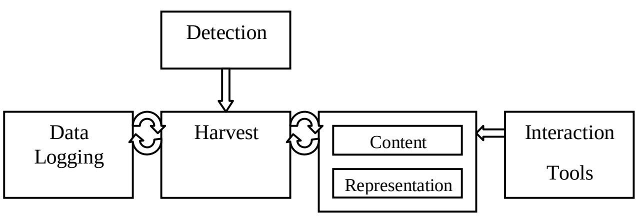

Figure 1: Model of dataflow in the SpeckNet

Detection: Making the user aware of the Specknet. The user will not necessarily know the location or characteristics of the network and so this will require initial detection.

Data-Logging: Actual operation of the Specknet in recording data

Harvest: Dynamic collection of data from the Specknet. As a real-time system it would be unfeasible to work with all of the data. Instead the user will control the nature of the data harvested.

Content: Description of data in the network. Since the user may not be aware of the nature of the sensor network, a description of the available data will be required in addition to the visualization.

Representation: Conveying the actual data values to the user

Interaction Tools: Provision of tools to control harvesting and visualisation will be an integrated part of the system.

4.1 Specktator

The next logical step was to develop an application to test the fitness of the dataflow model, and which incorporated the actual Speck technology (currently in its third generation and having dimensions on 40mm). A study was undertaken in which a group of users carried custom built Speck devices (a Specktator), which monitored their level of activity (through a pedometer) and interacted with other Specks placed within the environment.

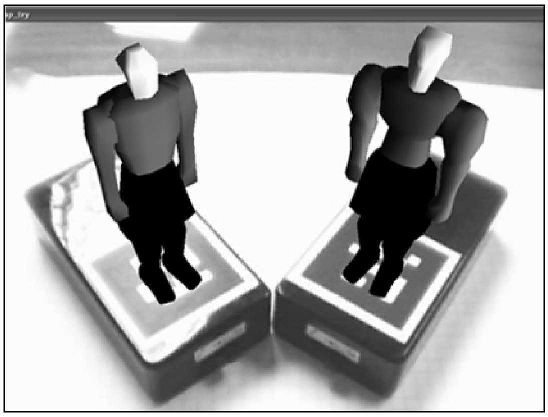

Figure 2: Character comparison for Specktators

The chosen scenario was for each Speck device to function as a virtual pet, where its appearance would reflect the underlying data (see figure 2). A semantic relationship was chosen where, for example, encounters with a Speck placed in a kitchen area would affect the appearance of the character's torso (from thin to fat), user activity would affect limb size, and visits to a print room would affect head size (which assumed printed documents would be of an intelligent nature). The decision to convey context via a feature and representation of a data value via the appearance of that feature is based on the work of Chernhoff who used faces to represent chemical samples [6], and Spence who used glyphs for both house and ship representations [13]. The aim is to present a recognisable link between appearance and underlying data.

In user trials the semantic relationship proved easily understandable, although perceived accuracy of the representations was low, and indeed it would have been impossible to view a character and determine for example how many trips had been made to the kitchen. However, as with

Chernoff's faces, the purpose was for comparison and for this the visualisation seemed appropriate.

5. MODEL OF INTERACTION

While previous studies explored the interaction with Specks directly in front of the user, they did not explore the potential scale of SpeckNets. A main feature of the SpeckNet is that it will be able to monitor entire regions of an environment, identifying interesting developments in specific locations.

Since the user is moving through an environment, interacting with different areas of the network, and then moving on to new areas; we chose as the foundation for our interaction model the path-finding works of Kuipers [8]. We identified three main sequential tasks, as shown in figure 3.

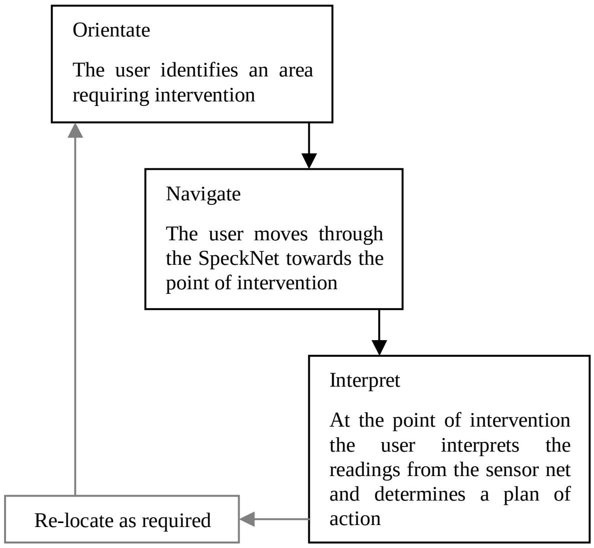

Figure 3: Model of Human-SpeckNet interaction

This model then served to focus our attention in a number of studies; starting with exploring user navigation, through the use of a virtual environment, and then exploring user interpretation of data in an AR environment.

5.1 Virtual Warehouse

Directing a user to a particular area of interest within the SpeckNet is problematic since we cannot assume that they have previous knowledge of the environment. As such, some sort of navigational aide is required to direct them towards the destination. In contrast to the majority of existing guidance applications (e.g. GPS road guides), a SpeckNet is not expected to easily have access to global environment information. It is expected that the network will be able to generate knowledge of its own distribution, but will have limited knowledge of non-speckled entities, and also limited knowledge of an environment's permeability to humans (i.e. the paths by which a person can move through the environment).

To explore these issues two methods of navigation were tested, with users placed in a virtual warehouse environment and tasked with collecting packages. One method was the familiar waypoint system used in the majority of navigational systems (in one form or another), whereby the user is given a sequence of points to pass through. The second method provided the user solely with relative information of direction and distance, as is minimally available in the SpeckNet.

Analysis of the results indicated that as expected the waypoint system was faster that the relative system, with the gap in performance increasing as the distance from start to goal increased. However, any unexpected obstacles removed this benefit to performance, which poses problems for the SpeckNet in gaining knowledge of non-Speckled portions of the environment.

5.2 AR Homefinder

In some SpeckNet applications requiring human intervention, the data interpretation phase may be trivial, in that the network need only identify the point of intervention (e.g. directing fire-fighters to a fire). In other applications the user may need to perform some exploratory analysis at the point of intervention (e.g. the ALife [7] system where the user must prioritise trapped avalanche victims).

Our most recent study focused on interpreting data from the network, once the user has arrived at the area they have identified as being of interest. The problem is in essence one of applying information visualisation principles to an AR environment. Specifically the study considers the appropriateness of the principles of overview, zoom and filter, details on demand, which were proposed as fundamental by Schneiderman [4].

The study composed of three stages. The first two stages compared a familiar point and click method of interaction against camera driven methods of interaction (i.e. where the interaction comes from the user's manipulation of the camera). The first explored details on demand, allowing participants to either click on objects to view their data, or target the object with the camera (gaze-selection). The second stage explored filtering through both a scroll-bar-style widget and tilting of the camera to adjust parameter ranges.

The final stage explored presenting an overview through the use of glyphs. The chosen scenario was presenting house and school information on a map. An example house glyph is shown in figure 4, and an attempt was made to create a semantic relationship between data and appearance. The building size was used to convey the number of bedrooms, the tree size to convey the size of the attached garden, and the platform height to convey cost.

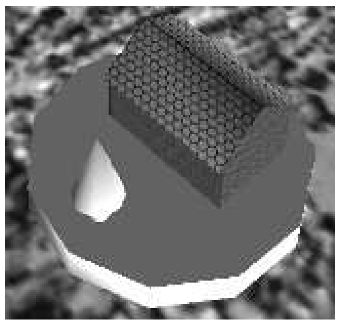

Figure 4: House data glyph

The study is ongoing and eight participants have been involved thus far. Initial results reflect the conclusions from the Specktator study with regards to the use of glyphs. In comparison tasks of identifying an extreme value, a group of similar values, and exceptions to a group, participants perform very well; in many cases identifying the target almost immediately. In terms of mapping values to glyph characteristics, participants intrinsically understood literal mappings such as house size conveying the number of bedrooms, but abstract mappings, such as platform height for price, required explanation.

Identifying actual values was still problematic, and so the inclusion of a 'details on demand' tool was useful. However the filtering tools were not seen as useful, most likely due to the relatively small dataset.

Camera interaction methods proved more challenging for participants than traditional GUI methods, but most participants reported them becoming easier to use through practice. This result over such as short exposure time indicates that the systems may be a useable system, but more design is required to improve efficiency.

6. SUMMARY

Thus far the project has looked at methods of interaction and visualization of data, as well as the requirements of navigational aides. The model of data flow has proven useful for understanding the operation of the network, and the interaction model appears promising, although its appropriateness will be tested fully in a future real-world application.

The next study will explore methods of orientating the user within the network, and identifying areas of interest. A system is required that will inform the user of the networks capabilities, allow them to set parameters identifying areas of interest, and then convey the distribution of those areas of interest so that a target can be chosen.

The aim is for the project to culminate in a study that draws together all of the information gained and apply it to a real-world application. As such it will include Speck technology in its intended (though admittedly on a smaller scale) role, and be evaluated by true users.

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