Tricorder: A mobile sensor network browser

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Abstract
In this paper we discuss some of the implications of wireless sensor networks in the context of mobile spatial interaction and, by way of example, give an overview of our "Tricorder" handheld sensor network interface.

Keywords
Tricorder, sensor network navigation, handheld, browsing, pointing interface

ACM Classification Keywords
H.5.2 Information Interfaces and Presentation: User Interfaces.

Introduction
Collections of cooperative, wirelessly networked, intelligent sensors embedded in our surroundings are poised to become integral parts of our everyday work and domestic environments. Although significant challenges must yet be overcome before ubiquitous deployment is realized, such wireless sensor networks are steadily creeping into our lives - cell phones, network-aware digital cameras, and RFID tags are already accepted as the norm. With them come challenging questions of usability and human-network interfacing. Should people be aware of the sensor nodes surrounding them? If so, how? How will people access, search, and sort the copious real-time and stored data available from wireless sensor networks? Will networks be open or closed, centralized or decentralized? Regardless of how these and similar questions are ultimately answered, their consideration will benefit from real-world examples of human interfaces to sensor networks. To this end, we introduce the "Tricorder" handheld wireless sensor network navigator and data browser, relate it to the state-of-the-art in mobile spatial interaction, and discuss new avenues of research therein.

Tricorder System Overview
The Tricorder is a location-, orientation-, and network-aware handheld device used to interface in real time to a wireless sensor network embedded in surrounding domestic and occupational environment. As the name suggests, the inspiration for the Tricorder comes from the fictional device of the same name from the original *Star Trek* science fiction television series. The fictional version of the Tricorder was a self-contained device capable of sensing relevant information about whatever it was being pointed at (e.g., life signs 50 meters back, magnetic disturbance above, or plot thickener ahead). Our Tricorder device aims to achieve the same goals, but rather than being self-contained, our Tricorder pulls sensor data off a surrounding wireless sensor network.

Physically, the Tricorder comprises a Nokia 770 internet tablet for display and user input purposes [9], a minimal radio node used to communicate with the surrounding embedded sensor network, a 3-axis compass with electronic gimbaling to ascertain absolute orientation in three dimensions with up to ±80° tilt [11], a battery pack power supply, and a plastic case to hold it all together. See Figure 1. Like the fictional Tricorder, our version knows in which direction it is pointing thanks to the compass. This, combined with coarse localization based on the radio's received signal strength indication (RSSI) from nearby embedded sensor nodes, allows for real-time point-and-browse functionality while physically roaming within the sensor network itself.

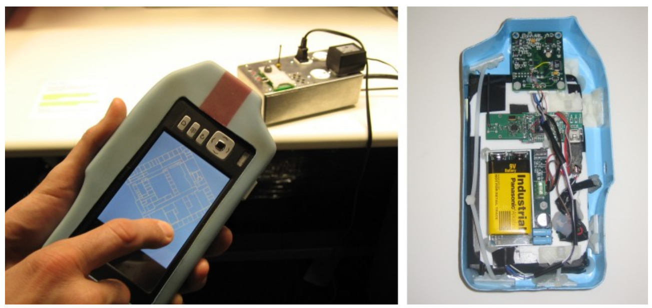

Figure 1: This Tricorder, inspired by *Star Trek*, uses a 3-axis compass to maintain the displayed map of our lab at a fixed orientation relative to the actual lab, allowing for a pointing interface to real-time, situated sensor data provided by the Plug sensor network nodes, an example of which is in the background (left). The opened backside of the Tricorder device shows the battery pack, radio, compass, Nokia 770, and glue logic used to connect the radio to the Nokia via USB and compass to the radio via a USART (right).

The Tricorder was designed for use with the Plug sensor network, a collection of 35 power strips enhanced with sensing, wireless communication, and computational capabilities [6]. The Plug sensor nodes are deployed just as regular power strips throughout the third floor of our lab. Each Plug sensor node can sense the electrical current drawn from each of its four electrical outlets, the electrical voltage supplied from the wall socket, sound, light, mechanical vibration, ambient temperature, and nearby motion. The data from these sensors are shared over a 2.4-GHz wireless radio network at up to half a megabit per second. The Tricorder's Plug-compatible radio can query nearby Plug sensor nodes directly or distant Plug sensor nodes by means of spreading a multi-hop request through the network and waiting for a response.

We've implemented a simple graphical user interface for the Tricorder. When using the Tricorder within the Plug sensor network, a map of the third floor is centered and oriented on the Tricorder's touch screen in real time according to the RSSI location estimate and onboard compass direction reading. Overlaid on the map are icons representing the Plug sensor nodes and their most recent sensor readings. The user can pan the map using the touch screen and zoom in or out using hardware buttons. Touching an icon reveals more detailed information about the corresponding Plug sensor node. Figure 2 shows a screenshot of the Tricorder's graphical display. At present, the representation of sensor data is quite literal and direct; more abstract and interesting visualizations are certainly possible.

The Plugs' multi-hop network allows for sensor data to be streamed even from far away nodes. These remote sensor streams, when combined with the orientation measurement from the compass, in a sense grant the Tricorder the power to “see” through whatever walls or obstacles obstruct its line of sight. In addition to communicating directly with the Plug sensor network, the Tricorder also has wireless Internet (IEEE 802.11) and Bluetooth capabilities, opening the possibility of accessing more traditional databases, websites, RSS feeds, cell phones, etc.

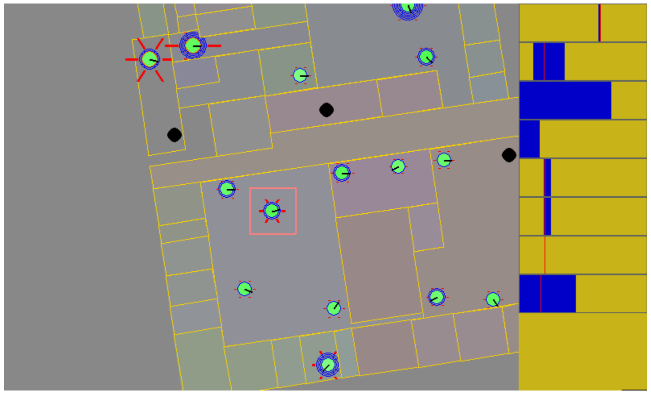

Figure 2: A screenshot of the Tricorder device showing the floorplan of our lab overlayed with Plug icons depicting sound (blue concentric circles), light (red radial lines), RSSI (green central circle), current consumption (black central dial), and motion (orange ring around the green central circle). The icons jitter slightly to represent vibration. The Plug icon enclosed in the pink square identifies the Plug from which the minimum, maximum, and average data for all sensor modalities are being shown in the bar graphs on the righthand side of the screen. Plugs can be selected automatically according to strongest radio signal, or selected manually via the touch screen.

Related Work

The Tricorder is related to various other works in both the wireless sensor network and mobile spatial interaction fields. In terms of using handheld devices in conjunction with a sensor network, the Great Duck Island sensor network project for monitoring the habitat of certain birds was among the first examples to use a personal digital assistant (PDA) as a management tool to fine tune the network [12]. Going beyond network management to conveying actual sensor data, a sniper localization sensor network system used a PDA to display the estimated location of a gunshot [7]. The Cricket indoor location system uses ultrasound pings between sensor nework nodes to provide handhelds with location information [1]. The concept of "participatory sensing" suggests using cell phones carried by people as nodes of a sensor network, wherin mobile devices form interactive, participatory sensor networks that enable public and professional users to gather, analyze, and share local knowledge [2]. Along the same vein, room-level localization and mapping have been demonstrated based solely on Bluetooth connectivity (as opposed to triangulation) in Bluetooth-rich environments [5]. Leaning more toward the concept of augmented reality [3] are the Periscope [14], Electronic Lens [8], and Point To Discover [4] projects, all of which attempt to tag the physical world with digital information and read the information back with the aid of a handheld equipped with some combination of GPS receiver, digital camera, and orientation sensor, all backed by a central information server.

Discussion

Although the Tricorder project is still very much in a developmental phase, the first working prototype strongly characterizes our vision of how people will interact with sensor networks. Our emphasis is on the sensing, not the networking, aspects of sensor networks. Certainly, networking is vital to any sensor network application, but the network serves primarily to transport sensor data gleaned from the real world. Moreover, the sensor data streams so generated should be accessible in real time to the people situated in the environment. This hints at our underlying belief that the most interesting applications for sensor networks will arise from people having access and creative license to use the sensor data being collected. In this sense, the Tricorder is a somewhat crude example of what the human-network interface could be.

Nonetheless, the Tricorder exemplifies certain design points. First, the Tricorder goes beyond sensing location; the purpose of the Tricorder is to browse the sensor streams from the surrounding sensor network. Second, the Tricorder is truly embedded; it does not rely on heavier infrastructure, such as the Internet and GPS, to access information about its physical environment. Third, the Tricorder is just another peripheral leaf in the sensor network; it is not central to the network's operation and contains very little intelligence of its own. All this said, there is no reason a future version of the Tricorder couldn't complement its current functionality by containing more intelligence, making use of Internet servers and GPS, and playing a more central managerial role within a sensor network. Indeed, there are good reasons to make these improvements.

A large branch of the human-computer interaction community subscribes to the notion that ubiquitous computing is in our future, that computers will be embedded throughout our environments and we will interact with them seamlessly. We argue that to make this vision a reality, the emphasis should not be on computing being embedded in our environments, but rather sensing being embedded in our environments. After all, the seamless interface we seek between people and invisible computers must rely on sensing. As an example of this skewed emphasis, Mark Weiser's seminal ubiquitous computing manifesto mentions sensing only once, and in passing at that [13]. Similarly, Steven Feiner's augmented reality manifesto mentions sensing mainly in the context of on-body sensing and ultrasound transmitters attached to objects [3]. We posit that sensor networks will be the technology enabling the human-computer interface necessary to realize ubiquitous computing. In this context, the Tricorder is by no means the final form this interface will take, but rather an example of an interface that emphasizes the important role of sensor networks.

Conclusions

The Tricorder is an example of a handheld mobile device that supports directional browsing of live sensor data gathered from a surrounding embedded wireless sensor network. The Tricorder emphasizes the importance of sensor networks as a step toward the seamless human computer interface for ubiquitous computing.

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