Enhancing Context-Aware Computing through Environmental Awareness

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Abstract
To counteract the rising complexity of mobile systems, context-aware computing is important to determine user intent and adapt devices accordingly. This position paper proposes to improve context detection by harnessing the fact that most modern devices have become detectable, networked beacons, allowing other devices to pick up their virtual presences and use these presences as indicators for the current physical environment. This paper proposes to improve context detection by a) analysing surrounding devices and b) communicating with nearby devices to exchange environmental status information. The paper describes the approach - both conceptually as well as technically - and describes possible use cases and limitations. We believe that further research in this direction can improve context detection in the future dramatically.

Author Keywords
context-aware computing; environment; context; bluetooth

ACM Classification Keywords
H.5.m [Information interfaces and presentation (e.g., HCI)]: Miscellaneous

Introduction
Modern devices, and in particular mobile devices, have rapidly gotten more powerful over the last couple of years.

With this, they gained new features but also became much more complex to use. For mobile interaction designers, this introduces new challenges: Users tend to use mobile devices to achieve a single task in a short time[2] with their cognitive resources being very limited[3]. But with complexity, the time to solve a task increases as well. As a prominent way to tackle this issue, research has looked into context-aware computing[1]. Context is a proxy for human intent[5] and as such helps to adapt applications to better aid the user. But detecting context is no trivial task: The components that make up "context" are manifold, ranging from location and time over lighting, temperature and noise to people and objects that surround us[1].

Current devices use a limited set of sensor hardware - such as GPS for location or accelerometer to detect motion - in combination with machine learning algorithms to determine context. While useful, this kind of context detection is very limited and insufficient to represent the complexity of people's life. Additional information about the surrounding could help devices to improve their context-aware behaviour. This position paper will focus on the possibilities of detecting the user's physical environment. We propose the use of short-range wireless technologies (i.e. Bluetooth Low Energy) to scan the user's current surrounding. By learning about repeating occurrences of combinations of devices (i.e. by using machine learning algorithms), and combining these occurrences with other sensor data (such as GPS, contact list data or the active application), it is our believe that context detection could be largely improved. The basic approach is not novel in itself - for example, ContextPhone has described the use of "physical environment, including surrounding Bluetooth devices"[4] as a possible sensor. We think, though, that this kind of sensing has tremendous potential to improve context-aware computing and is not sufficiently explored yet, in particular in light of recent advances in technology. Therefore, this paper will describe an approach of a) context sensing using surrounding devices and b) retrieving extended environmental information through communication with nearby devices. We will further detail different use cases where this detection can improve application behaviour and describe the limitations and technical difficulties in making this approach a reality.

Context through Surrounding Devices

With the advance of Weiser's vision of ubiquitous computing and the emergence of the Internet of Things, almost any modern device communicates with the outside world. Wi-Fi, Bluetooth, and NFC have become prominent communication channels and are found in smartphones, tablets, and computers, but also watches, light bulbs, fridges, TVs, and many more devices. It is likely this trend will continue in the future to incorporate even more types of devices. We believe this fact can be harnessed by scanning and learning about the surrounding of a device to derive context information.

For example, consider workplace detection using location. While suited for regular work at a single workplace, such a detection will fail for a travelling salesman or for extraordinary events, such as external meetings or a dinner. Using surrounding devices, the detection of the work context becomes much more adaptable. During work-related events the user is surrounded by a similar circle of devices: The personal devices of co-workers. Based on this, work events can then be correctly classified. By querying additional sensors, such as time and location, the context can be further narrowed down: For example, at a restaurant in the evening, the work event becomes a dinner with colleagues. Using this knowledge, devices can adapt, e.g. by turning off non-crucial notifications and giving quick access to culinary information such as wine ratings.

In contrast, consider being at the same restaurant at the same time but being surrounded by close friends: Here, all notifications would be enabled, taken photos could be automatically shared, and, when leaving, the location of bars with long opening hours can be suggested.

Environmental detection can also provide valuable metadata for artefacts. While scribbling down digital notes during a meeting, the artefact can be automatically tagged, e.g. with the project name. When taking a photo, face detection can be improved based on the people present and the photo can further be tagged with the people *not* seen on the photo. Advanced activity tracking, such as determining how long the user spent on his work computer or how often he went up to get coffee, can provide valuable insights for a healthier lifestyle.

Detecting surrounding devices can also provide an indicator for the current level of publicity. When interacting with a large display, the number and type of nearby people can influence the displayed information: With no one nearby, personal information such as the next appointment can be disclosed. At a public place with lots of people nearby, only limited information, such as the time to the next appointment, but no details, are shown.

It is our believe that an environment-based approach to context detection will lead to more adaptable and robust results and performs better at translating to actual user intent.

Enriching Environmental Information

So far, the focus has been on the presence or absence of surrounding devices to determine context. Using modern communication technologies, environmental information can be enriched by allowing devices to retrieve additional information from their surrounding. This information can vary: Most importantly, the type of nearby devices can be retrieved. Devices can also allow to retrieve their current state, for example the currently running movie on a TV or the measured temperature on a thermostat. This enables an even deeper integration with the environment. This kind of exchange can be performed through the same ad hoc communication channels as the detection of devices, such as Bluetooth or NFC.

Such advanced environmental information further enhance a device's ability to adapt. For example, retrieving the currently running movie from a TV allows for second-screen information on the smartphone, such as the actors in the current scene. Knowing the exact type of training tool the user is currently working out at enables advanced fitness tracking through accelerometer and heart rate sensors.

We think that a standardised exchange of local environmental information combined with the refined context detection described previously can enable entirely novel ways of how our devices sense their surrounding and adapt to it.

Technological Approach

Most of today's off-the-shelf consumer devices feature the hardware required for environmental detection. Most prominently, Bluetooth Low Energy is built into almost any modern device. Even home automation devices (such as light bulbs) are often Bluetooth-enabled. Additionally, technologies such as NFC have become more commonly available and could enable cheaper sensing of devices in the future.

Detection of surrounding devices can be done with simple Bluetooth scans. Paired with additional sensors (such as GPS), using information from the user's contacts list, and combined with fuzzy machine learning algorithms, a robust detection of context can become possible. For simplicity, for abstraction and to protect user information such a detection should be implemented on an OS-level, handing only

high-level context information to applications. Detailed information, such as the exact devices and people in a user's surrounding, should not be handed to applications.

Exchanging environmental information can be done using the same technologies. Developing a common protocol amongst all the different devices in our environment is required in order to achieve a seamless communication between these devices. This is difficult, in particular considering the large variety of possible devices. A high-level protocol that allows devices to register predefined device types and capabilities, similar to how most home automation protocols work, could tackle this issue, but also restricts flexibility. Applications could register for the desired device types and properties to receive updates about them from the OS. Mixing such a static protocol, implemented on an OS-level, with the ability to exchange a limited amount of custom data, implemented at application level, could enable a trade-off between abstraction and flexibility. For example, this would allow TVs to advertise themselves as a screen device, but also broadcast the current movie for applications interested in this information. Nonetheless, the communication between all different types of devices remains the largest issue in this approach, and an issue in cross-device interaction and ubiquitous computing in general.

Limitations

In a real-world implementation, mapping of virtual device presences to people, which is required for some scenarios, can be difficult. For example, Bluetooth Low Energy alternates the MAC address of a device regularly to make it untraceable. And even with traceable devices, matching devices to contact list entries can still be a difficult task. Also, such a mapping can be considered a security risk and must be implemented with care to ensure user privacy. The excessive data exchange between devices could furthermore exceed the bandwidth possibilities of Bluetooth and a large amount of signals could lead to interference. Future technologies might be able to solve such technical issues.

Furthermore, context remains only a proxy for human intent, and environmental detection does neither guarantee that the context is correctly determined nor that the context is correctly translated into intent. Certain scenarios will remain difficult to detect. This, of course, is a general issue with context detection and can only be improved by further research in this direction, development of better sensors and improvement of algorithms.

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