Typical Sensors needed in Ubiquitous and Pervasive Computing

Michael Beigl, Albert Krohn, Tobias Zimmer and Christian Decker
Telecooperation Office (TecO), University of Karlsruhe
{michael, krohn, zimmer, cdecker}@ teco.edu.

ABSTRACT

This paper presents a survey of sensors for the use in networked embedded sensing devices. The most typical sensors needed for applications in Ubiquitous and Pervasive Computing are identified through a survey of 12 typical existing and implemented applications using over 300 wireless sensor nodes. In total, about 45 different types of objects with embedded networked sensor nodes build the basis for the analysis. We identified 7 general types of sensors - namely movement, light, force, temperature, audio, humidity and proximity - that are commonly used in all these settings and subsequently listed typical context information that can be derived from them. Based on the analysis the paper also introduces an exemplary platform, the Particle Sensor Board, where such sensors are implemented and presents an overview of their characteristics.

Keywords: ubiquitous and pervasive computing, networked embedded sensor systems, applications, sensor platform

1. INTRODUCTION

Many applications are being found for networked embedded sensor systems, especially in ubiquitous and pervasive computing settings. Several platforms are available to fulfill these tasks such as Berkeley MOTES [1], Dolphin [2], or Prototype Embedded Networking (PEN) [3]. They are mobile, communicate wirelessly and are small enough to be embedded into many palm sized everyday objects. One of the primary tasks of such networked embedded nodes is to gather context information - e.g. information about the situation in the environment or the condition of an artifact. To sense physical parameters such as temperature or movement these nodes are either embedded into everyday objects or the environment itself. This paper presents an analysis of several Ubiquitous and Pervasive Computing applications and identifies the most important sensors and their sensed physical parameters. The analysis was based on application scenarios using embedded sensor nodes rather than environment based sensing. Based on the survey sensor implementations are selected taking into account additional characteristics such as low energy consumption and small size. An example implementation of a board that is of general use in these settings is then presented.

2. ANALYSIS

While location sensing was at the center of interest during the early development of Ubiquitous and Pervasive computing, today's research is more diverse [4]. This paper concentrates on sensors, suitable for use in small, cheap devices, which capture physical parameters from the environment or objects, acting as input to functions that determine their general contextual information.

Application Area

Ubiquitous and Pervasive Computing environments are typically researched and developed by means of rapid prototyping. A common approach is to use off-the-shelf networked embedded systems or to design and implement specialized hardware, which is then *post hoc* attached to an existing object or into the environment (figure 1).

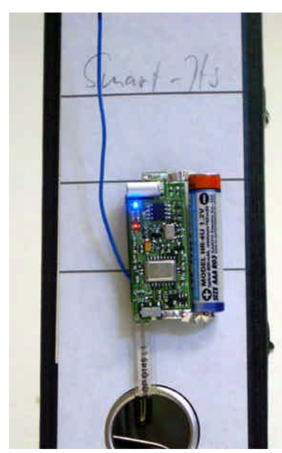

Figure 2: Wireless sensor node used for paper document tracking

The process of sensing can be optimized and simplified by using a general sensor platform that provides the most common sensors on one board. To find this useful set of sensors, we analyzed 12 scenarios with over 300 sensor nodes to find the most important sensors for Ubiquitous and Pervasive computing. Although these scenarios cannot be seen as completely representative for Ubiquitous and Pervasive Computing they provide a good overview of many settings including workspaces (office, industry etc.), home and leisure with the exception of healthcare and wellness. The analyzed scenarios included fully running prototypes and applications that are in daily use. We built up or cooperated in the design of all scenarios, which gave us access to all necessary information for the survey. The scenarios include MediaCup [5], AwareOffice [6], TEA [7], MemoClip [8], Smart-Its applications [9-13], Aware Goods [20], eSeal [14], DigiClip [15], ContextAsAKey [16], Trust Context Spaces [16], UbicompBrowser / Electronic Manual [17], Point&Click [18]. All scenarios include networked sensor nodes embedded into different classes of objects. In total, about 45 different types of objects with embedded networked sensor nodes form the basis of the analysis. This includes objects of the following object classes: *tools* (e.g. pen, clip, screw driver), *furniture* (e.g. chair, table, shelf), *objects that contain non-organic material* (e.g. box, packet), *objects that contain organic material* (e.g. can, cup, plate, flower pot), *information objects* (e.g. paper, doorplate) and *consumer electronic devices* (e.g. coffee machine, camera, video recorder, TV set).

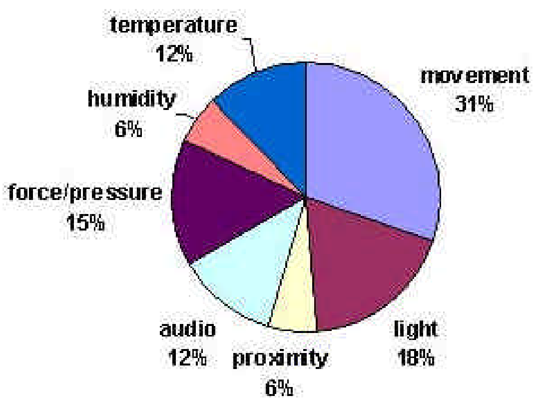

Figure 2: Sensors types used in applications

Physical Parameters and Type of sensors

Each of these object classes has preferences regarding sensors used to detect the contextual status of the object itself and of situational context of the surrounding environment. In our analysis of the over 300 sensor nodes, we found 7 general classes of physical parameters that provide interesting information to objects with networked embedded sensor nodes:

Movement (including type of movement as "being used", "running", "standing still", plus acceleration, rotation and vibration), *force* (including weight measurements and force attached to various parts of an object), *light* (in various wavelength like daylight or infrared light including parameters like light level and change over time), *temperature* (in various places of an object as environment temperature, temperature of an object laying on or filled into the object or temperature of the object itself), *humidity* (in various places as humidity of the environment or humidity inside the object), *audio* (including noise level, frequency spectrum but also the changes over time), and *proximity/activity* detection of the environment.

The distribution of sensors among the analyzed applications (figure 2) shows a clear preference to sensor types for movement, followed by light and force/pressure. Observably, these sensors are especially suited for activity recognition in the application and of the object to which the sensor is attached e.g. to derive the *general internal context* of an object. When looking at the distribution of used sensor types, among the over 300 analyzed wireless sensor nodes (figure 3), two more sensors must be added to the list of most used sensors: temperature and audio. Both sensors are commonly used to derive information about the environment of the object to which a sensor node is attached. These sensors are therefore useful for deriving the *situational context* of an object.

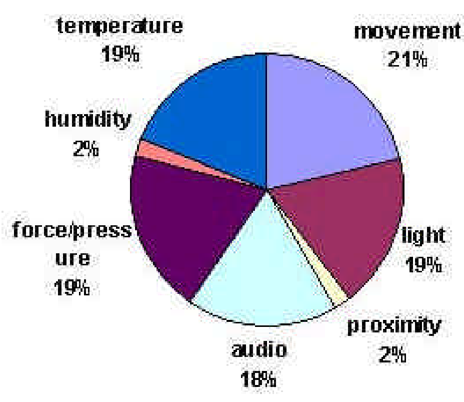

Figure 3: Sensors types used in sensor nodes

The general distribution of sensors is also similar when analyzing the used sensor types per type of objects. The reason for this is that although most applications running on embedded sensor nodes on an object use only some of the sensor types additional sensors are used to detect the situational context in the environment which leads to the use of an overall similar set of sensors no matter what type of object is analyzed.

3. SENSORS SURVEY

For a successful prototype in Ubiquitous or Pervasive computing settings, the selection of the right sensor must primarily consider restrictions of form factors and energy consumption as most of these devices are embedded into everyday objects making many of them rather small in size and used in mobile scenarios. The following paragraphs give an overview of the examined sensors and explain the implementation and application issues.

Movement

The detection of simple movements and movement patterns of objects has been an effective component in many application settings. The most elementary context that can be detected via such a sensor is "moved" e.g. to trigger a “wake up” event for a processor in sleep mode. In 10 out of 12 analyzed settings, devices were mostly only active when they are grabbed by the user and therefore moved. Furthermore a movement sensor can determine the movement state of an object and distinguish e.g. between activity levels or even recognize special conditions or situations. In the MediaCup, we can detect if someone is holding the cup, drinking or if the cup just sits on the table. Other contexts detectable are vibration e.g. for sensors built into environments to detect situations as earthquakes.
Movement Sensor. The most popular movements sensors are ball or mercury switches. The ball switch is much more sensitive and can react very fast and even detect vibrations coming from sound sources. It only requires one digital I/O line to the microprocessor and consumes *no extra power* besides the output signal.

Acceleration

This sensor can replace the simple movement sensors but can also go beyond. In the analyzed applications we found that the acceleration was an important source for supervising conditions of sensitive goods [14]. The acceleration vector of a moved object is an excellent source for generating shared context of physically collocated objects, e.g. for context proximity. In the Smart-It friends [12] application objects compare their acceleration vectors and can decide whether they are together in a compound or not. Acceleration sensors can as well be used to measure the earth’s gravitational force on an object to determine its angle of orientation relative to the ground. One example usage scenario was to find the orientation of furniture parts during the assembly process in the Smart Furniture [13].
Acceleration Sensor. Because of the size and the power consumption, only MEMS types of acceleration sensors are applicable on a small and wireless device. They have accuracies down to some mg resolution at update rates around 100 Hz, sufficient to determine movement patterns or to measure angles with respect to the earth’s gravity, yet not enough to realize inertial navigation systems. In comparison to simple movement sensors their power consumption is higher and their response time is lower, plus their values are of much broader use.

Light

Measuring light intensities at various wavelengths is mainly used for detecting environmental conditions. Precision is less important than efficiency – especially power consumption – and flexibility in the choice of the detected wavelength. Combining measurements from different spectral areas allows distinguishing between light sources such as sunlight or artificial light as they all have their typical spectral distributions. Typical contexts that can be acquired include abstract location decisions according to the light pattern. E.g. in the TEA project light sensors are used to decide whether a person was outside or indoors. In cases of no movement sensor the light sensor may serve as a replacement by processing the knowledge of how movement influences the light level on parts of a moved object.
An additional benefit of such sensors is their use in low power data communication. The limited distance of the propagation of light signals makes it the ideal choice for building location beacons as in the MemoClip application and other IrDA SIR standard based systems.
Light Sensor. To minimize the package size of the light sensor, parts with integrated filters and amplification are preferred, as they do not require additional circuitry. Available sensors either generate an analogue value representing the light level or are standalone sensors with a digital interface like I2C. A major problem of most cheap low power light sensor types is that their sensitivity range is limited. Applying different optical filters can solve this problem. Such light sensors are normally rather inexpensive and small and therefore find application in many settings.

Proximity

Similar to the movement sensor, the detection of proximity of a subject can be used to launch applications that are inactive when no user is around. In contrast to other sensor types this sensor directly provides a simple context without interpretation, namely the “subject is around” context. Derived contexts are (human) activity level in an environment that can be derived from the pattern delivered by proximity sensors [6].

Proximity Sensor. Determining proximity is in most cases done with passive infrared sensors or capacitive sensors. They normally carry an integrated design and signal whether activity in an observed area can be detected. These sensors are still rather big and consume considerable amounts of energy as compared to other sensors listed here. Their use is therefore only valuable in dedicated settings.

Audio

Analyzing audio information from the environment can be useful for understanding the context of a mobile device. Even simple algorithms can already produce valuable information. The sound level can lead to conclusions about the activity level in a certain surrounding and zero crossing detections can inform about the sound source and distinguish between speech, music, male female speakers or situations such as in a car or in a meeting. Moreover, sound is a local, very unique and fast changing context and provides a good basis for automatic generation of keys or to find nearby objects using context proximity algorithms [16].

Audio Sensor. Typically, audio sensing needs 3 parts: the microphone, the amplifier and the A/D converter. For the conditions of small package and low power operation only capacitive microphones are applicable. Design of the amplification is restricted by available space and power consumption which makes the resulting audio sensor subsystem suitable for analyzing environment noises and speech in rooms of up to 40 m^2. Applications requiring extensive analysis of signals beyond 10 kHz or requiring high signal to noise ratio are beyond these simple audio sensor subsystems. Still many audio algorithms can be implemented to work on-the-fly without the need to store the sampled audio values, which is an exhausting task on small processors with limited resources.

Temperature

Interesting temperature values are those of an object (e.g. for a liquid in a cup) or of environmental temperature. For both measurements flexibility of use and robustness is more important than precision of the device. In many cases not the temperature value itself in degrees but a differentiation between some states is sufficient. The MediaCup e.g. has only three temperature distinctions - “cold” and “warm” and “hot” reflecting more high level context of the object. Temperature sensors are as well used for product monitoring during transportation [14].

Temperature Sensor. Temperature sensors are available as e.g. temperature sensitive materials (PTC/NTC) that require contact to the object to be measured or as infrared sensors that measure the radiation. The easiest way is to use integrated sensors connected via a bus like I2C. These sensors are very small and easy to use. As temperature normally changes rather slowly, the period for measurements for a continuous monitoring of temperature in typical pervasive computing settings is in the 10 seconds range. This makes a temperature sensor very low power in its mean consumption.

Mechanical Force

Touch or force sensors are useful to detect situations like “object is lying on the desk” by simply applying it on the bottom of the object. Depending on the sensor, more differentiated context can be derived through e.g. measuring the weight of a glass and from there concluding to the fill level. Change of weight distribution over time can also be used to conclude on activity type context, such as “a subject is nervous while sitting on a chair”. In a simpler manner, mechanical sensors may as well be used as an interface and act as a tangible interactive medium. In the SmartFurniture application, force sensors were used to find out whether parts of furniture were fastened together by simply placing these sensors between the connecting parts.

Force Sensor. Foil type force sensors fulfill the criteria for small outline, low energy consumption and flexible attachment. They can be selected in the measurement ranges from 1g to some kg (equivalent weight) but are normally not designed for precise measurement without elaborate calibration. Such sensors fit quite well to measure the force of a human hand or the weight of portable objects.

Humidity

Sensing the air humidity is useful for reasoning about both environmental and internal conditions. This measurement can be exploited in the monitoring of goods during transportation that are sensitive to humidity such as paintings. Collaborative readings of these sensor values in buildings, together with temperature and vibration, provide the basis for analysis of status of such constructions.

Humidity Sensor. Often humidity sensors are just a net of small printed wires on a material measuring the resistance of that material which strongly varies with the humidity it is exposed to. When used in construction such sensors are often separated from the rest of the sensor electronics and embedded into the measured object, e.g. into concrete. For measuring environmental humidity intelligent sensors with integrated amplification and a digital data bus are available.

Experimental Values	Current for measurement	acquisition energy	mean power	typical price (100+)
Light Sensor TSL 25x/ 26x	**100µA(bright) - 760µA (dark)**	**53µJ**	**2.5mW**	**1.10 €**
Light Sensor TSL2550 (ambient light,I2C)	**400 µA**	**480 µJ**	**1.1 mW**	**1.70 €**
Acceleration Sensor ADXL210	**640µA**	**188µJ**	**3.2mW**	**10 €**
Temperatur Sensor TC74 (I2C)	**300µA**	**150 µJ**	**1.0 mW**	**1.00 €**
Capacitive Mic +opamp lm4880	**1600µA**	**(160µJ)**	**8mW**	**6 €**
Touch Pressure Sensor FSR-151AS + lm324	**600µA**	**156nJ**	**16µW**	**7 €**

Table 1: Comparison of Sensors

4. EXAMPLE BOARD

In our Particle Computer sensor platform we selected the sensors listed in the table 1 for usage in a generic sensor board. The table summarizes some of the important parameters such as acquisition energy – the energy needed from sleep mode of the sensor until first valuable reading – and the mean power – the power consumed for a continuous reading of the sensor. This selection is based on applications explained in section 2 and 1 and completely covers with the exception of the proximity sensor all sensing tasks in all mentioned 12 scenarios. The sensors form a powerful aggregation for a general sensing device. Figure 4 shows a photo of a fully equipped Particle Computer sensor board [19][21] which has been used widely in academia and industry in a very small scale (19x35 mm). The board also contains an own embedded processing unit (back side) and an interface to other sensing or wireless communication boards [10]. These additional features allow the board to process context information at the sensor node, store data and to communicate such data between sensor nodes. Access to functionality is provided via a simple set of Application Programming Interfaces (APIs) that are integrated in the Sensor Nodes Operating System running on the processor.

5. CONCLUSION AND OUTLOOK

The given selection of sensors and the now available general embedded sensor hardware platform was of great help for developing Ubiquitous and Pervasive Computing applications. Workshops with novice users showed that development of small applications can be carried out in less than two days. The feedback we collected from users in research and industry indicate that more complex applications can be set-up within a week, which is a great reduction of development time compared to previous approaches. Together with the users of our Particle Board system we will further optimize our system regarding performance and lower energy consumption. An increasingly important issue we are currently looking into are software development tools that support rapid prototyping but also the overall process of application development.

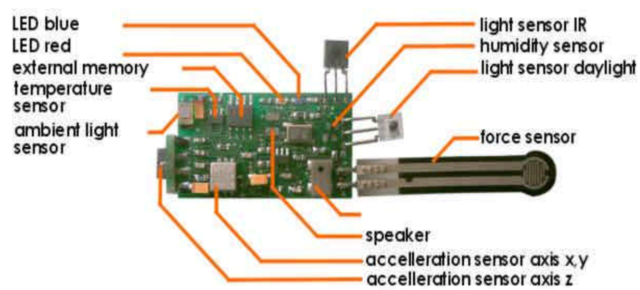

Figure 4. Particle General Sensor Board sized 19x35mm

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REFERENCES

[1] Estrin, Culler, Pister, Sukhatme, .Connecting the Physical World with Pervasive Networks. IEEE *Pervasive Comnputing*, Vol. 1, No. 1, pp. 59-69

[2] Minami, Morikawa, Aoyama. Prototyping a Fully Distributed Indoor Positioning System for Location-aware Ubiquitous Computing Applications, Ubicomp 2004

[3] Girling, Kam Wa, Osborn, Stefanova, The Design and Implementation of a Low Power Ad Hoc Protocol Stack. Wireless Communications and Networking Conf. 2000

[4] Schmidt, Beigl, Gellersen: There is more to context than location, Computers & Graphics Journal, 1999

[5] Beigl, Gellersen, Schmidt. MediaCups: Experience with Design and Use of Computer-Augmented Everyday Objects, Computer Networks Journal, 2001

[6] Aware Office Initiative. http://www.teco.edu/awareoffice/

[7] Schmidt, Aidoo, Takaluoma, Tuomela, van Laerhoven, van de Velde, Advanced Interaction in Context". HUC 99

[8] Beigl: Memoclip: A location based Remembrance Applicance, HUC Conference 2000

[9] Beigl, Krohn, Decker, Robinson, Zimmer, Gellersen, Schmidt. Context Nuggets: A Smart-Its Game. Ubicomp Conference 2003

[10]Beigl, Gellersen. Smart-Its: An Embedded Platform for Smart Objects, Smart Objects Conference (sOc) 2003

[11] Beigl, Robinson, Zimmer, Decker: Teaching a practical Ubicomp course with Smart-Its, Ubicomp 2002

[12] Holmquist, Mattern, Schiele, Alahuhta, Beigl, Gellersen, Smart-Its Friends: A Technique for Users to Easily Establish Connections between Smart Artefacts, Ubicomp Conference 2001

[13] Holmquist, Gellersen, Kortuem, Schmidt, Strohbach, Antifakos, Michahelles, Schiele, Beigl, Maze. Building Intelligent Environments with Smart-Its, IEEE Computer Graphics, January 2004

[14] Decker, Beigl, Krohn, Kubach, Robinson, eSeal - A System for Enhanced Electronic Assertion of Authenticity and Integrity of Sealed Items. Pervasive 2004, Wien

[15] Decker, Beigl, Eames, Kubach. DigiClip: Activating physical documents. IWSAWC 2004, Tokyo, Japan

[16] Robinson, Beigl, Trust Context Spaces: An Infrastructure for Pervasive Security in Context-Aware Environments, Conference on Security in Pervasive Computing, 2003

[17] Beigl, Schmidt, Lauff, Gellersen: Ubicomp Browser, ERCIM Workshop on User Interfaces for All, 1998

[18] Beigl: Point & Click - Interaction in Smart Environments, HUC Conference 1999,

[19] Beigl, Zimmer, Krohn, Decker, Robinson, "Smart-Its - Communication and Sensing Technology for UbiComp Environments" Tech. report Univ. of Karlsruhe, 2003

[20] Thede, Schmidt, Merz. Integration of Goods Delivery Supervision into E-Commerce Supply Chain. Electronic Commerce Workshop 2001.

[21] Particle Computer Website. http://particle.teco.edu