# µParts: Low Cost Sensor Networks at Scale

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### ABSTRACT
This paper presents the µPart wireless sensor system especially designed for settings requiring a high population of sensors. Those settings can be found in actual research of indoor activity recognition and ambient intelligence as well as outdoor environmental monitoring. µParts are very small sensor nodes (10x10mm), with wireless communication, enabling the setup of high density networks at low cost and with a long life time. Basic configuration capabilities like sensor type and sampling rate provide enough flexibility while keeping the system easy to deploy and affordable at the same time.

### Keywords
low cost wireless sensor network, particle computer

### INTRODUCTION
Networked sensor systems have attracted more and more attention in the last years. Various systems were developed in research and industry (e.g. Motes, Smart-Its, EYES, Ember, MITes, U3, BT-Nodes). The typical architecture of those systems includes wireless sensor nodes that typically communicate over multi-hop radio links. The embedded microcontroller often preprocesses the data or takes over important tasks of the applications distributed across the network. These systems aim to support research in various disciplines such as healthcare, environmental monitoring and ubiquitous computing in general. In the latter they typically support monitoring and tracking of people and objects and their activity or interaction.

### DENSE SENSOR NETWORKS FOR RESEARCH
Taking a closer look into the typical use of the above mentioned sensor network in nowadays, activity recognition and ambient intelligence [1] are the major use cases of sensor networks for indoor setting. Outdoor settings mostly focus on large area coverage with multi-hop communication. For both fields of application, it is of high interest to increase the number of independent sensors above a critical number. The authors of [1] could track people and recognize their activity using very simple sensors that only distinguish between binary values such as “moving” and “resting”. They concluded that the algorithms would work more robust and accurate once the number of sensors is significantly increased. This aspect of research using dense settings of sensor networks promotes a *new and alternative system design* of a sensor network, that focuses more on these requirements and reflects the experiences researchers have collected with existing sensor networks.

For large-scale and dense real-world deployment of a sensor network, some properties of the individual sensor nodes and the system as a whole must be rethought. In [2] the authors implemented a sensor node system only transmitting RF pulses according to the intensity of movement. While this is extremely bounded to one application, researchers require more flexibility. We now summarize the important features to realize a setting that exceeds the experiments possibilities with nowadays available sensor networks.

- **Low price**. Sensor networks are today available for typically between 100€ and 200€ per sensor node. Settings that use more than 100 sensor nodes quickly produce investment costs that prohibit to carry out the desired research or require to reuse a set of sensors for different purposes. Therefore, the target price for a single sensor node should be significantly reduced. The µParts have a target price of around 15€ per node.
- **Limited computation.** Even though most of the sensor networks available today carry a programmable microcontroller, the local capability of computation is often only used for data transport. The application software often requires complex data processing that is typically implemented on high performance machines like desktop PCs.
- **Configuration.** To realize a flexible system that can be used in various settings for different purposes, a certain minimum capability of configuration is essential. This configuration normally includes solely the choice of sensor and the sensor’s sampling rate.
- **Simple sensors.** The complexity of an individual sensor can often be balanced out by the use of many simple sensors. Theses simple sensors cut down the cost and also produce very easy to interpret data.
- **Long lifetime.** Especially large scale settings with high numbers of sensor nodes involved require a long life

time. A setting with e.g. 1000 sensor nodes running for several years with an individual sensor node lifetime of one year would in average require 3 battery replacements per day. This is unacceptable especially for highly embedded settings where sensor nodes are integrated into furniture or placed in other difficult to reach locations.

- **Topology.** The optimal topology for a sensor network is very application dependent. Nevertheless, in many settings the radio distances are small enough that multi-hop communication is not necessary. It is also possible to separate the sensor nodes from the pure networking nodes and build a system of sensor nodes and additional routers. The ratio between the costly routers and the sensor nodes is typically very small.

The above mentioned properties are crucial for research that requires large settings and/or dense sensor node population. Nowadays sensor networks provide capabilities for settings where nodes are mobile and need to transport data over a long distance via multi-hop communication. However, most of the technical features are not continuously used in the deployed systems resulting in unnecessary higher costs and size of the single network end-points. It also negatively affects the overall lifetime of such sensors. As a consequence, the computational power and communication capability is then often artificially reduced by introducing sleep times and low duty-cycle TDMA protocols.

### μPart: THE TECHNICAL SYSTEM

With the μPart-System, we present a sensor network that is built on a minimum hardware and software basis. This system just fulfills the minimum requirement to enable research supporting the above mentioned areas. The small and cost-efficient design enables large-scale settings with high sensor density, but without the need of a high monetary investment. The capability of reconfiguration promotes it for the flexible use in research and opens up a wide area of use cases.

The μPart sensor node (Figure 1) comprises a PIC microcontroller with 1.2k Flash ROM and 64 byte RAM, two sensors, RF transmitter and a battery integrated on a 10x10 mm PCB footprint. Current sensor configuration are light, tilt, temperature, motion and acceleration. The communication interface transmits sensor data with 19.2 kBit/s in the European 868MHz ISM band.

**Figure 1: A μPart Sensor Node (1 cm³ incl. battery)**

The μPart sensor nodes are supported by a network of routing nodes as depicted in Figure 2.

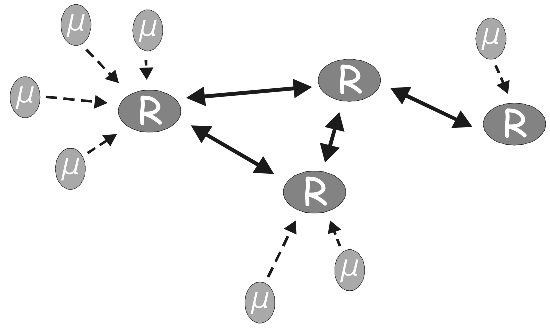


**Figure 2: The μPart network topology, consisting of μPart end-nodes and routers**

The routers implement the communication for data transport and self-organizing overlay functionalities. They act like a traditional sensor network with out-sourced sensors. The μParts as well as the routers encode data as strictly-typed tuples using our ConCom [3] language. This typing allows the integration of μPart networks in heterogeneous settings where applications benefit from μParts' dense sensor information as well as from other sources. The μParts seamlessly integrate into the particle computer[1] network.

### REMOTE CONFIGURATION OF μPARTS

With the use of the light sensor on the μParts, configuration is possible through the transmission of modulated light. This modulated light can be produced by a flickering image or short video played on any screen of a PDA, computer or DVD player etc. The μPart is then simply held in front of the screen and can receive the modulated light transporting the configuration information. This also enables a mass configuration of the μPart System by simply shining on a large group of μParts with a modulated light source (such as a computer screen). The use of a screen as configuration interface has the advantage of ubiquitous availability and needs no extra hardware avoiding any compatibility problems.

### REFERENCES

1. D.H. Wilson and C. Atkeson. Simultaneous Tracking and Activity Recognition (STAR) Using Many Anonymous, Binary Sensors. Proceedings of PERVASIVE 2005, Munich, Germany, May 2005
2. J. Paradiso, M. Feldmeier. Ultra-Low-Cost Wireless Motion Sensors for Musical Interaction with Very Large Groups. Presented at the UBICOMP 2001 Workshop on Designing Ubiquitous Computing Games, Atlanta GA, Sept. 2001.
3. A. Krohn, M. Beigl, C. Decker, P. Robinson, T. Zimmer, ConCom – A language and Protocol for Communication of Context, Technical Report ISSN 1432-7864 2004/19

[1] http://particle.teco.edu