Personal Aerosol Samplers

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Personal aerosol samplers are used to measure the exposition of a person to particulate matter. There are two main application areas for such instruments: in occupational hygiene, workers can wear such a personal monitoring device, thus giving an estimate of their exposition. In addition, if the instrument provides an online reading, an alarm level can be set, above which the instrument warns the workers that exposure levels are too high. For this type of application, it is crucial that the personal monitor is robust and simple to use, since untrained personnel will be asked to wear it. The second main application is in the study of aerosol-related health effects: the measurement of personal exposure gives a direct link between exposure and effect (e.g. through a lung function test), unlike the often used in vitro and in vivo (animal) studies. These are indispensable tools for assessing particle toxicity, but nevertheless they may not be representative for health effects caused in humans. An online instrument is also desirable for studying health effects, since a short-term high exposure may lead to a different effect than a constant exposure with the same average value.
Current methods to measure personal exposure include filter-based gravimetry (with or without impactor inlet), simple light scattering devices, and handheld condensation particle counters (CPC). All of these instruments have serious drawbacks when used for personal monitoring: filter-based methods have a low sensitivity, offer 24-hour-averages at best, and require trained personnel to avoid artefacts when weighing the filters. Light scattering instruments have an instrument response which depends in an erratic way on particle diameter, refractive index, and structure, which makes the commonly used calculation of a mass from the light scattering signal problematic, to say the very least. Handheld CPC's require a working fluid, and must be held substantially level to avoid flooding of the optics. They are great tools for rapid assessment of particle number by a qualified technician, but cannot be used for personal monitoring where the worker hast to be able to move freely.

In this presentation, we show two instruments that we developed during the last year, which help to address the personal aerosol exposure measurement challenge. The first one is the electrical diffusion battery (EDB). It is based on the electrical charging of particles, followed by subsequent detection in multiple size-selective deposition stages, where the deposition of charged particles produces an electric current that can be measured with sensitive electrometers. The deposition in the size-selective stages takes place due to diffusion, i.e. smaller particles with larger Brownian motion are more likely to be deposited. Therefore, the measured current in the first such diffusion stage corresponds to very small particles, the one in the next stage to larger particles, etc. The instrument response is not very sharp, i.e. monodisperse particles deposit on multiple stages, which complicates the data inversion process, and leads to a poor size resolution when compared to traditional instruments such as the scanning mobility particle sizer. On the positive side, the instrument can be miniaturized - our current prototype is just 10x24x24 cm and weighs 5kg. With a serious engineering effort, the size and weight could be reduced by another factor of two. The EDB measures particles in the size range of 10-300nm, and particle concentrations from ~1'000 to 1'000'000 particles/ccm. It also has a very high time resolution of about 1 second. Thanks to an internal battery and data storage on a standard memory card, it can be operated in a backpack for up to 12 hours. Of course, the instrument is far too heavy for long-term personal monitoring, but it is the smallest and lightest instrument available that is able to measure particle size distributions, and as such may be interesting for short-term exposure studies. We validated the performance of the EDB by comparing it with a TSI fast mobility particle sizer (FMPS) in an on-road campaign conducted by Paul Scherrer Institute on the Gotthard route, Switzerland's main alp transit route with a large traffic volume. The two instruments typically agree to within 20% in particle number, mean diameter and geometric standard deviation. As an example of personal exposure measurement with the EDB, the first author carried it with him on the commute home after work. The personal exposure is dominated by the few minutes in Zürich main station, where different aerosol sources are present, such as smokers and sausage grills.

For "real" personal monitoring, i.e. for studies where the personal exposure is measured for weeks or even months, the personal sampler must be reduced much further in size and weight. We achieved this by removing the size-selective diffusion stages from the instrument, which gives a well-known instrument, the so-called diffusion charger (DC). DC's are available commercially, however, they are all desktop instruments with a weight between 7 and 9 kg, and thus cannot be used for personal monitoring. Our engineers miniaturized our DC to make a prototype that is 10 times smaller and lighter than the existing commercial instruments. DC's measure a signal that is proportional to the particle diameter d to the power of ~1.1 - the exact value of the exponent in the power law depends on the charger used. The charge that the particles acquire does not depend on the particle composition. The instrument response can be tuned by changing either the charging process or the detection process. Instead of using diffusion charging, where particles acquire an average charge q proportional to $d^{1.1}$, field charging can be used, where theoretically the response is proportional to d^2. Studies on existing field chargers show charging proportional to much lower exponents (around 1.4), which is most probably the result of combined field and diffusion charging. Our own version of a combined field-diffusion charger produces a charge proportional to $d^{1.35}$. A carefully designed field charger which minimizes diffusion charging might give a larger exponent. On the detection side, selective detection of small particles can be realized using a single diffusion stage (as used in the EDB) instead of the filter stage. This gives an instrument response which is very close to d^0, or in other words, an electrical particle number detector. Electrical mass measurement might be possible following an idea by Andreas Schmidt-Ott of TU Delft: If field charging close to d^2 is possible, then larger particles have a larger electrical mobility than smaller particles after the charger, and selective deposition by electrophoresis of the larger particles would lead to an instrument response close to d^3. This is however just a theoretical concept until now. For our personal sampling prototype we have so far achieved tunability from $d^{0.3}$ to $d1^{.35}$, and as mentioned above, the upper limit of this tuning range might be extended further.

In our prototype design, we placed special emphasis on simplicity, and also on "manufacturability", i.e. there are few components, and the result is that the instrument will be relatively cheap compared to current diffusion charging instruments. The availability of cheap, reliable instruments would also open up other applications, for example, the addition of a mobile phone chip to the device would make ad-hoc measurement networks possible, which could measure particulate matter with much higher spatial resolution than it is being done currently - today, most instruments are too expensive for such large-scale networks.

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Why personal samplers?

Paracelsus (1493-1541):

„Dosis sola venenum facit“

(The dose makes the poison)

Risk ~ Toxicity * Exposure

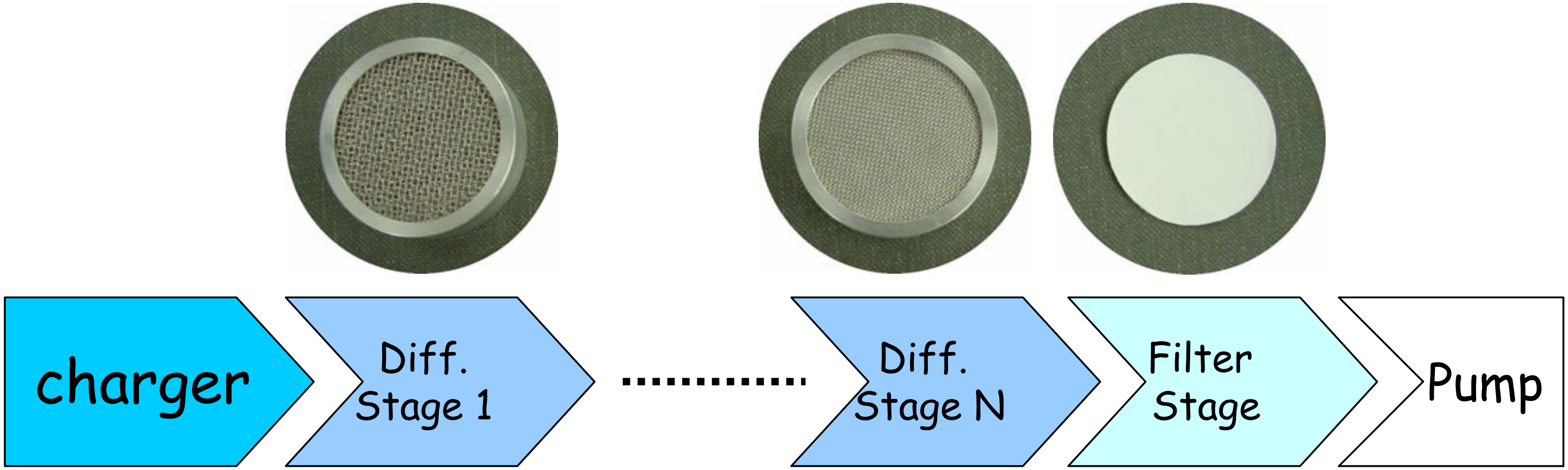
Why personal samplers?

- Industrial/Occupational Hygiene:
  Detection of potential health hazard,
  -> warning in real time (online)
  -> simple to operate

- Medical studies:
  Direct link between exposition and human health
  (cf. Petri dish, rats)

Electrical diffusion battery

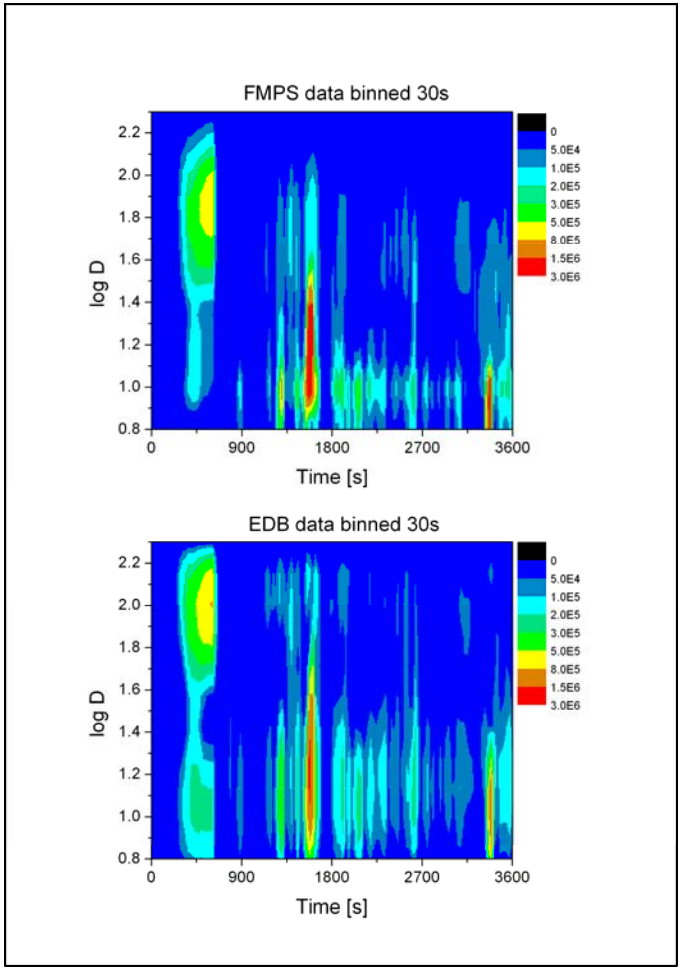
- Charge particles by diffusion charging
- Detect them with electrometers
- Use diffusion stages (screen stacks) for particle size classification



Electrical Diffusion Battery

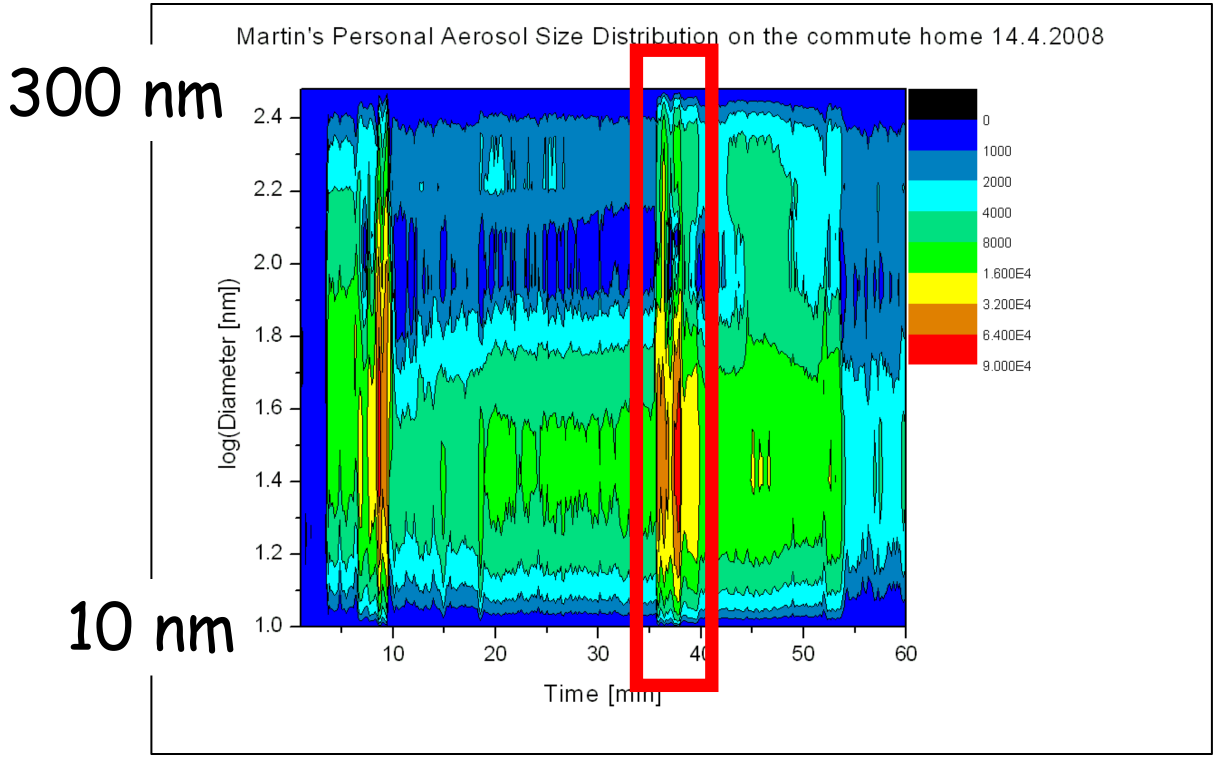
- Battery powered
- Portable (5kg, 24x24x10cm) (1/2 possible?!)
- Size range: ~10...300nm
- Concentrations: ~1E3...1E6 pt/ccm
- Time resolution ~1s

EDB vs FMPS



EDB was compared against a TSI fast mobility particle sizer (FMPS) during an on-road campaign in southern Switzerland with the PSI mobile lab „Mosquita"

EDB personal monitoring

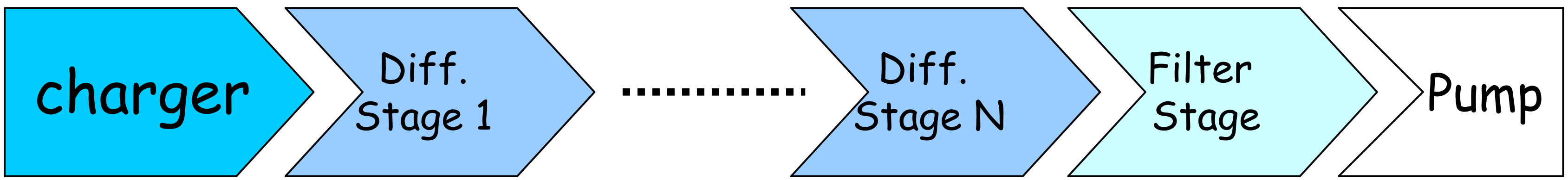


Zürich main station
Smokers,
Sausage Grills etc.

Note: for personal monitoring good time resolution is necessary!

DiSC

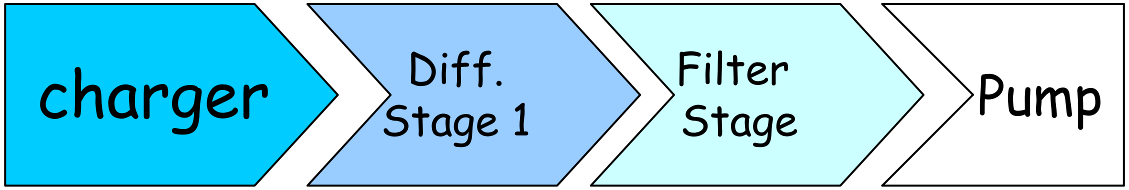
- Simplify by reducing number of diffusion stages to 1: „Diffusion Size Classifier“



- Gives particle number + average diameter

Reduce further

- For personal monitoring, instruments have to be very small+light
- Reduce to a single electrometer stage



- This already exists: diffusion charger (DC)

Existing instruments

- TSI nanoparticle surface monitor (NSAM)
- TSI Aerotrak 9000
- Matter Engineering LQ1-DC

- 7…9 kg

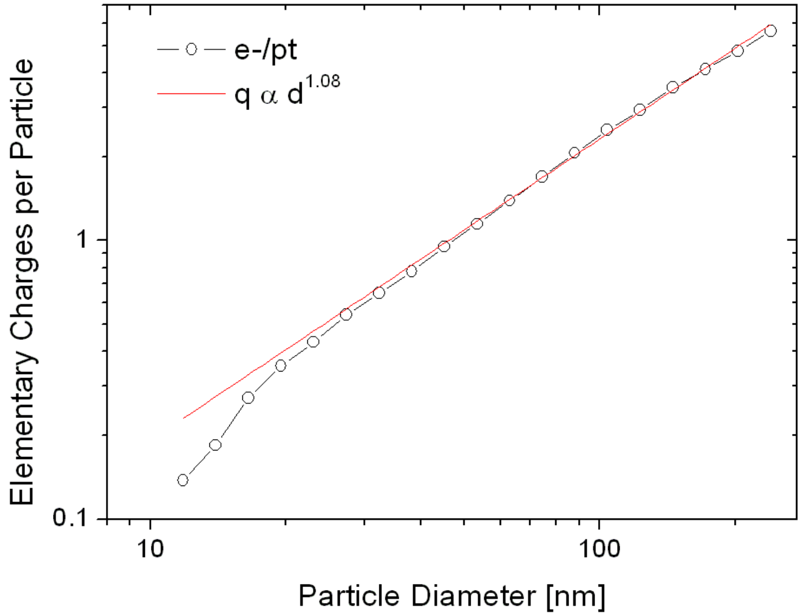
Personal Monitor Prototype

- 770 grams
- 9h battery life
- 45x82x180mm

- Detection limit ~300 pt/ccm @ 100nm
- 10x smaller and lighter than existing diffusion charging instruments

What does it measure?

- Diffusion charging leads to a charge proportional to $d^{1.1}$
- Charge does not depend on particle composition



Tunable response!

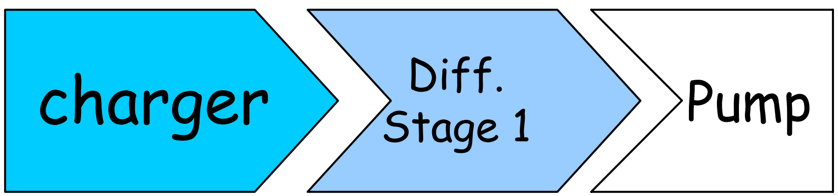
- Use field charging instead of diffusion charging => d^2 (surface)
- Use selective detection with diffusion charging => d^0 (number)
- Use selective detection with field charging => d^3 (mass)

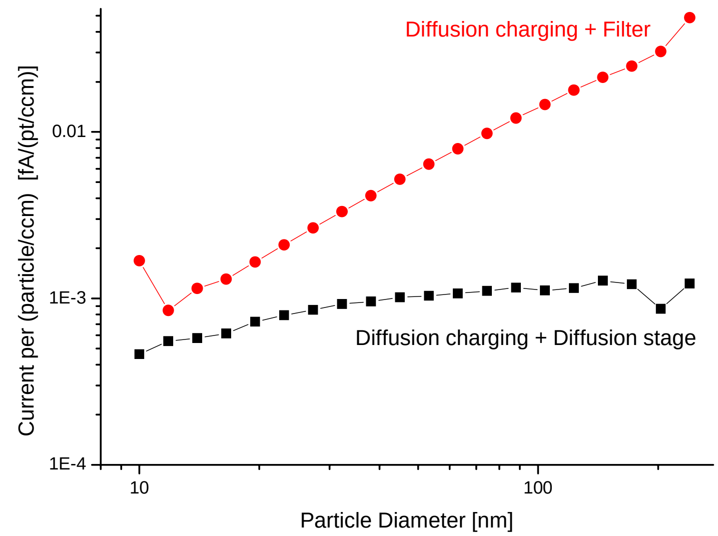
Why tunable response is good:

- On a per-mass-basis smaller particles seem to be more dangerous than larger particles
- Use a metric which gives smaller particles more weight (d^0,d^1,d^2?) instead of mass (d^3)

Selective detection example

- Capture particles by diffusion: instrument response is nearly independent of particle size: „electrical particle counter“ EPC

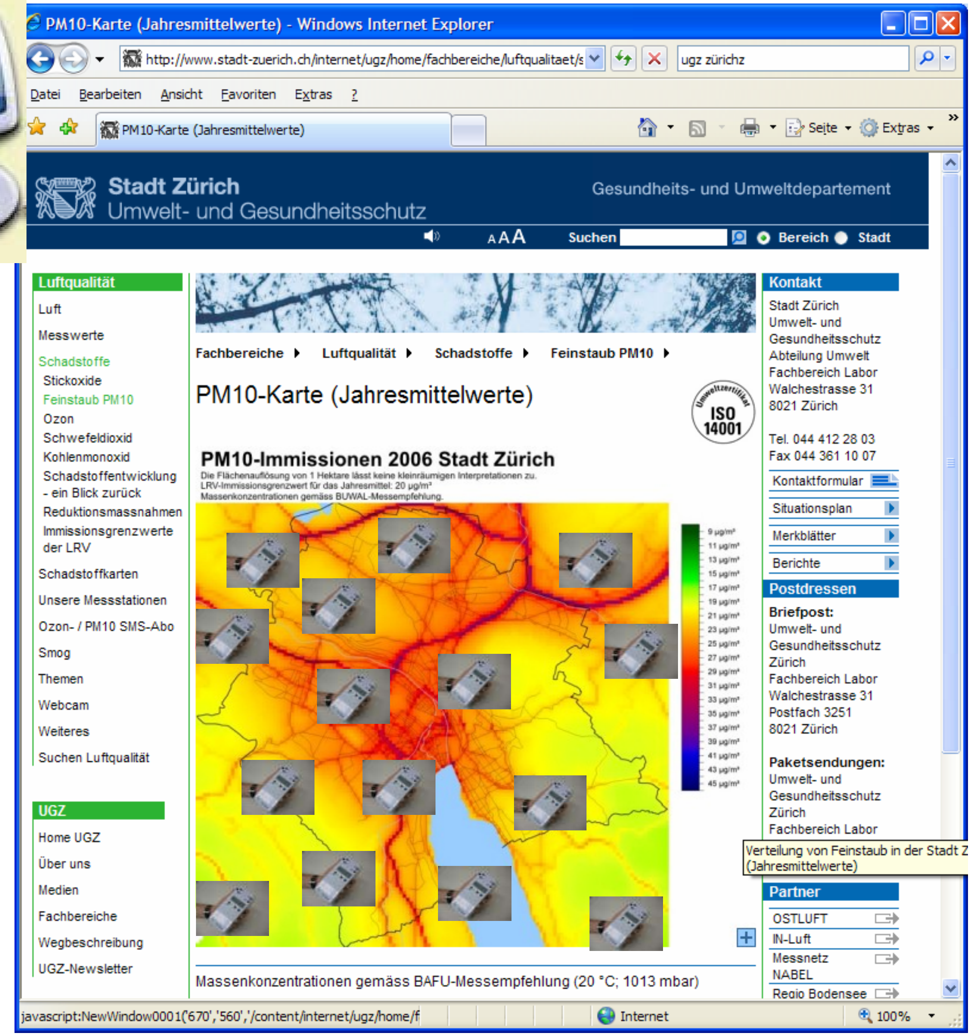




Conclusions for charging

- Electrical Diffusion Battery can be used to measure „personal size distribution", but it's too heavy for long use
- Simple, very light charge-based personal samplers with tunable weighting: d^x, x = 0…1.x (2,3?!) can be built
- Measurement is physical, i.e. particle composition is not detected
- This is currently the only technology capable of detecting ultrafine particles online in a compact, simple instrument

Monitoring Network



Take home

- Charge-based personal samplers are a good alternative to existing instruments; much more sensitive for ultrafine particles; online
- Instrument response can be tuned in a wide range
- This technology can also be used for low-cost measurement networks with high spatial resolution

Acknowledgements

Work

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