Information Processing Theory in Measurement

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Contents

Providing thinking tools for design and evaluation of measurement systems

Essence of the problems

Primitive model of measurement

Q : Quantity you want to know

V : A sensor output reflecting Q as $V = f(Q)$

Estimate $Q = f^{-1}(V)$

Actual measurement

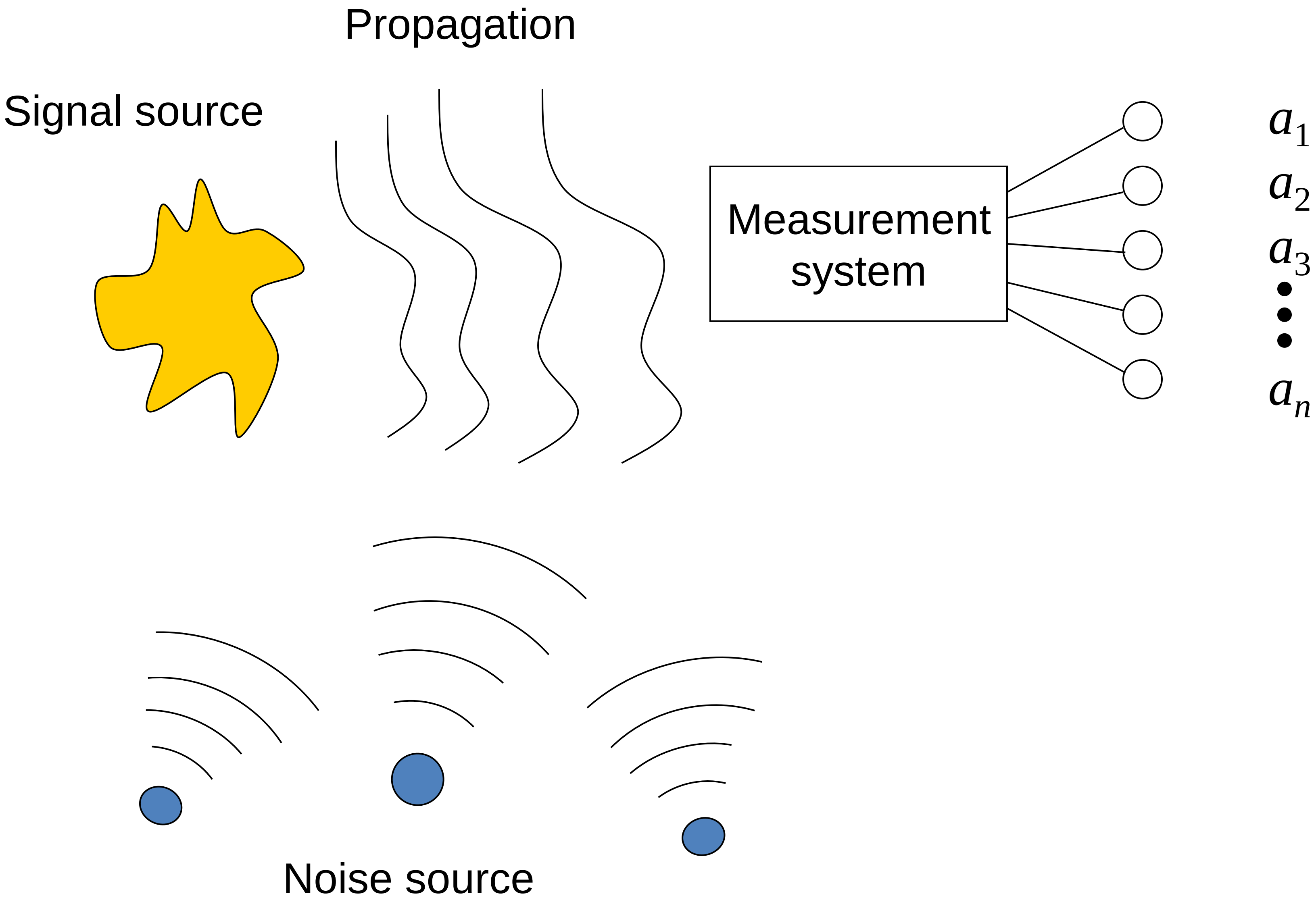
V also depends on other quantities other than Q, and affected by noise.

The problem addressed in this lecture

Estimating Q from a measured value vector

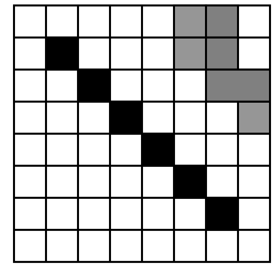
$$\mathbf{V} = (V_1, V_2, ..., V_n)$$

What is the best estimation under noise?
What is the best design of the measurement system to minimized the estimation error?


Propagation
Signal source
Measurement system
a_1
a_2
a_3
a_n
Noise source

Patterns

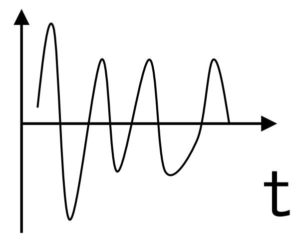
1） Spatial pattern



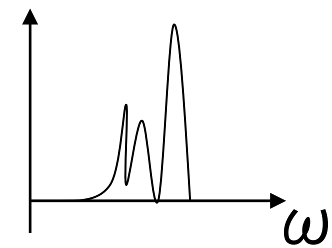
Image

Photo --- 2D
Video --- 3D

2） Temporal pattern



Time



Frequency

3） Physical parameter pattern

Optical spectrum, force vector,...

4） Pattern of patterns

Examples of pattern measurement

１） Taking a photo

- What determines the resolution limit?
- Noise reduction limit by signal processing
- Finding a specific person

２） Wi-Fi communication

- Method to find the signal sent to you when many people communicate simultaneously.
  → What is the difference between measurement and communication?

３） Others

- Is it possible to record only the voice of a specific person?
- Precision of sound localization

Examples of pattern measurement

- Precision of GPS
- Sensors in cars, rooms, and everything.

Today's lecture ～Overview of problem

(1) Breakthroughs of pattern measurements

(2) New problems in IoT

The goal of the class

- Evaluation of precision in pattern measurement
- Design of measurement system
- Understanding information in pattern

(1) Breakthroughs of pattern measurements in 20th century

- Point measurement to pattern measurement
- Information by pattern
- Learn the common expression in various kinds of pattern measurement

1．Scanning
   Conversion from space to time
2．Array device
   Measuring 2D pattern
   Device fabrication by lithography
3．Aperture synthesis
   Generalization of lens
4．ＣＴ (Computed Tomography)
   --- Solving an inverse problem
5．Separation of signals by spatial modulation
   --- MRI, Structured light

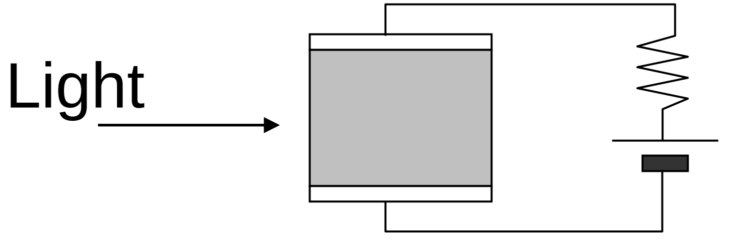
1. Scanning: the first step of pattern measurement

Example: Measuring 2D light and dark pattern

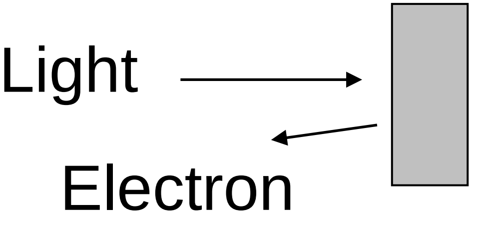
Beginning

○ Discovery of material whose carrier number changes by light

Si, Se, CdS, CsSe, ・・・

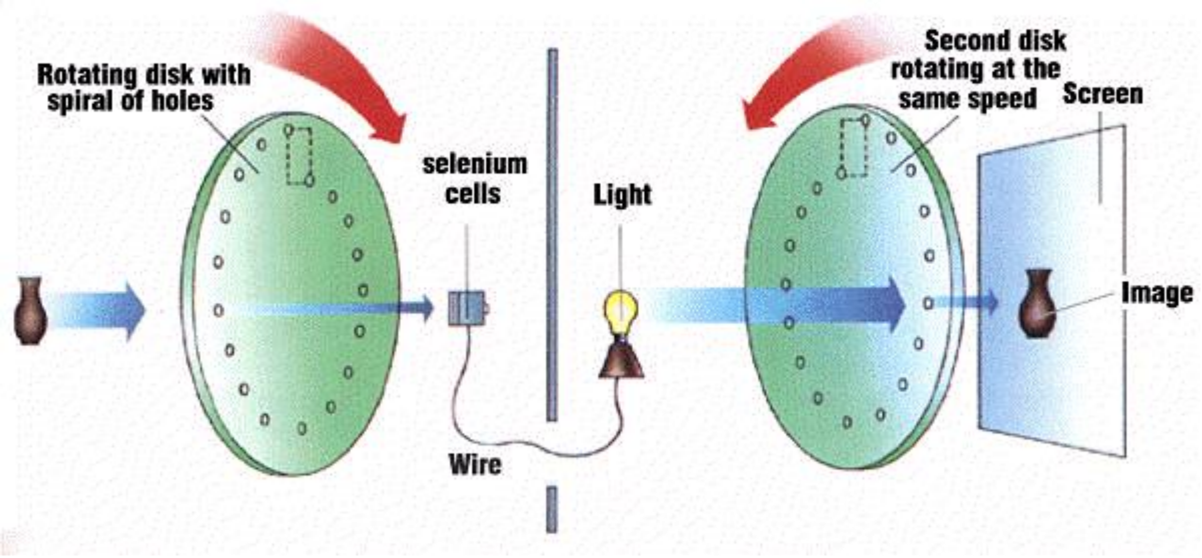


○ Photoelectric effect



Mechanical TV

Paul Nipkow 1884

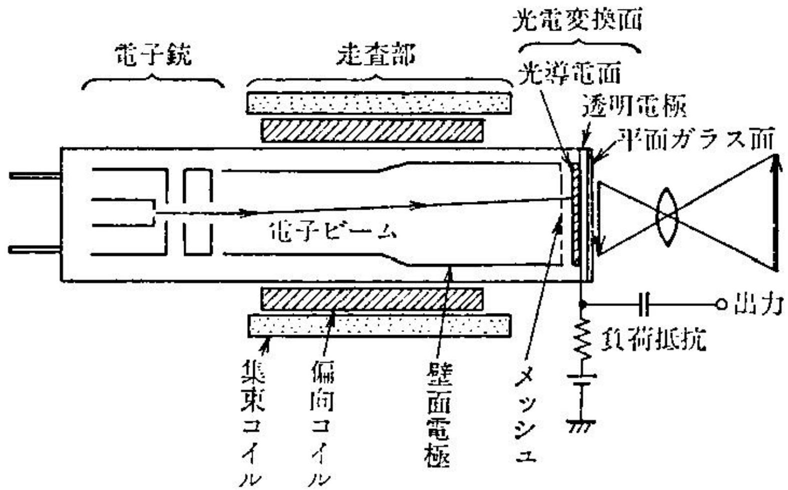


http://www.databahn.net/library/inet/history/tv/

Scanning with an electron gun

Iconoscope
Vladimir Zworykin 1929

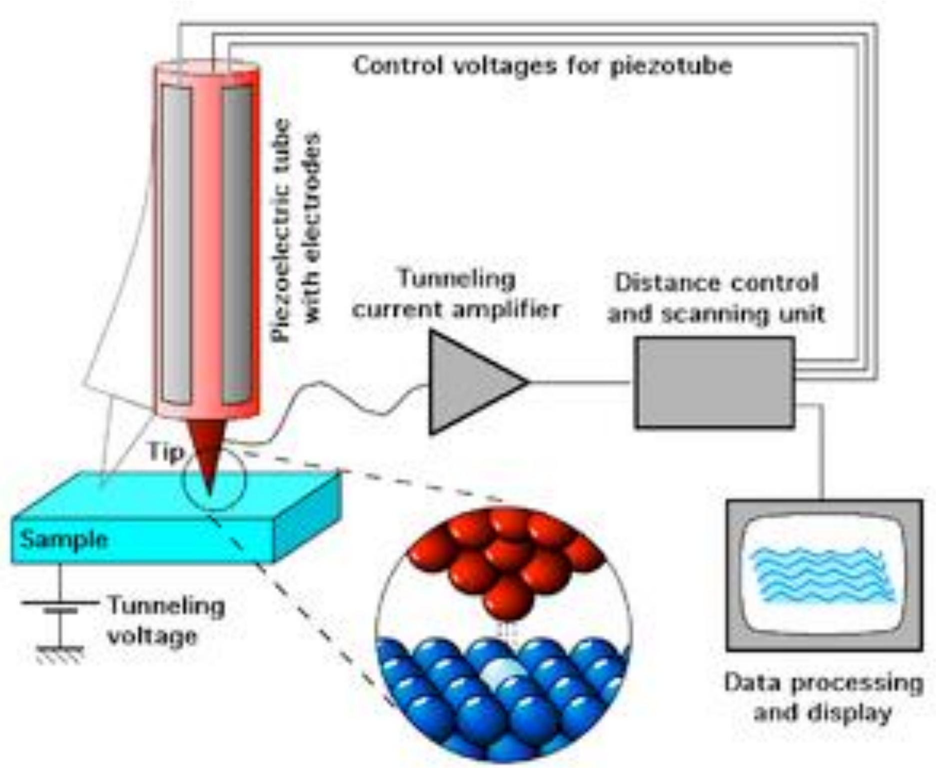
Vidicon tube 1950 ～
Use of photoconductive effect

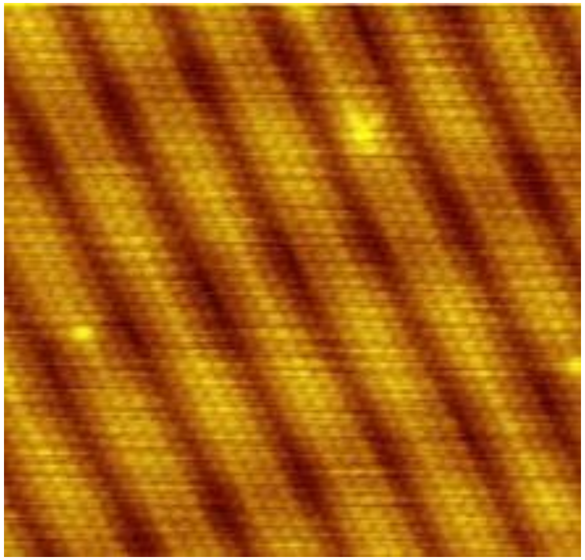


Drawing with electron gun

- CRT (cathode ray tube) for oscilloscope, Karl Braun 1897
- Displaying “イ" on a CRT Kenjiro Takayanagi 1926～27

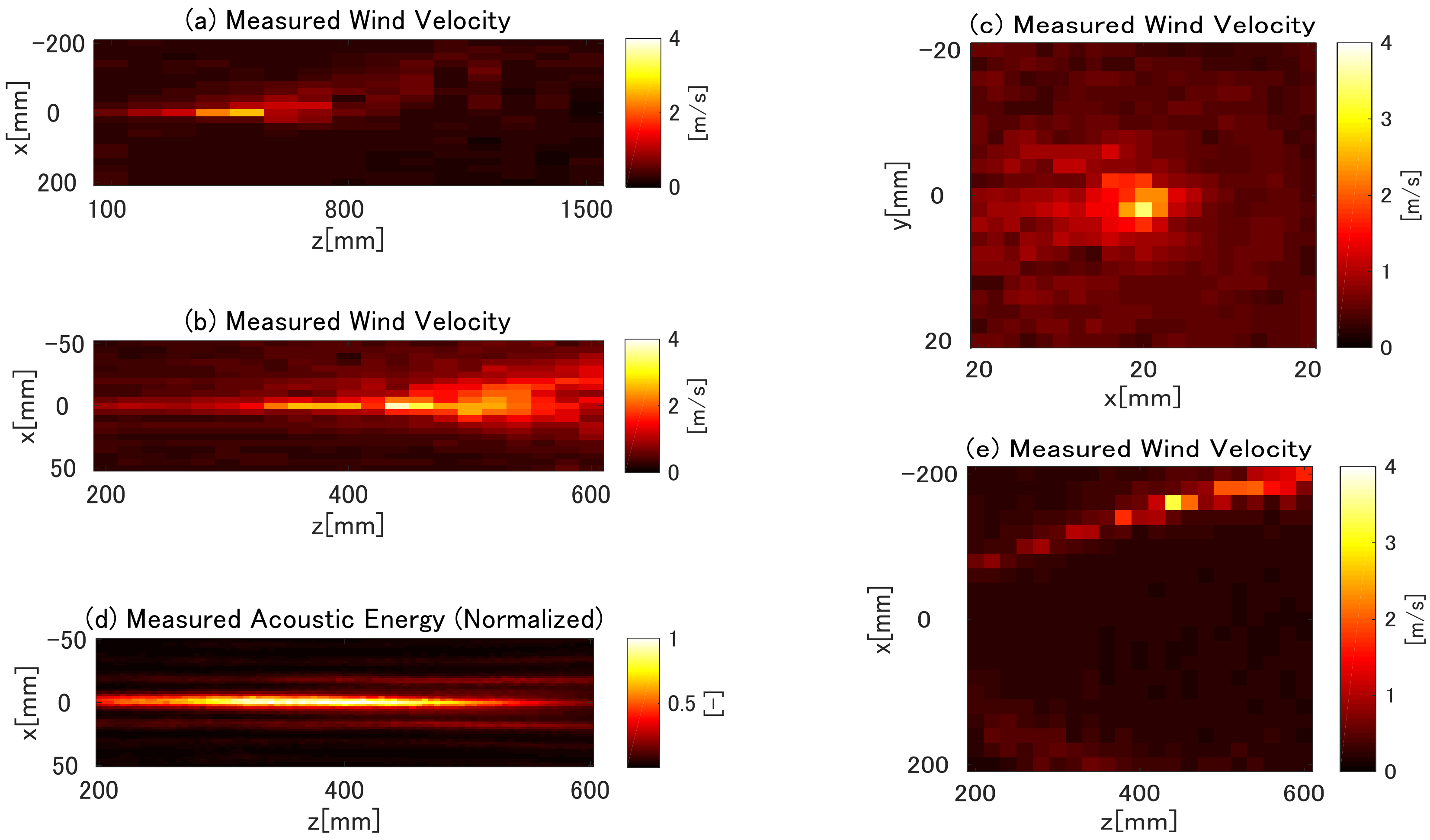
STM (Scanning Tunneling Microscope)

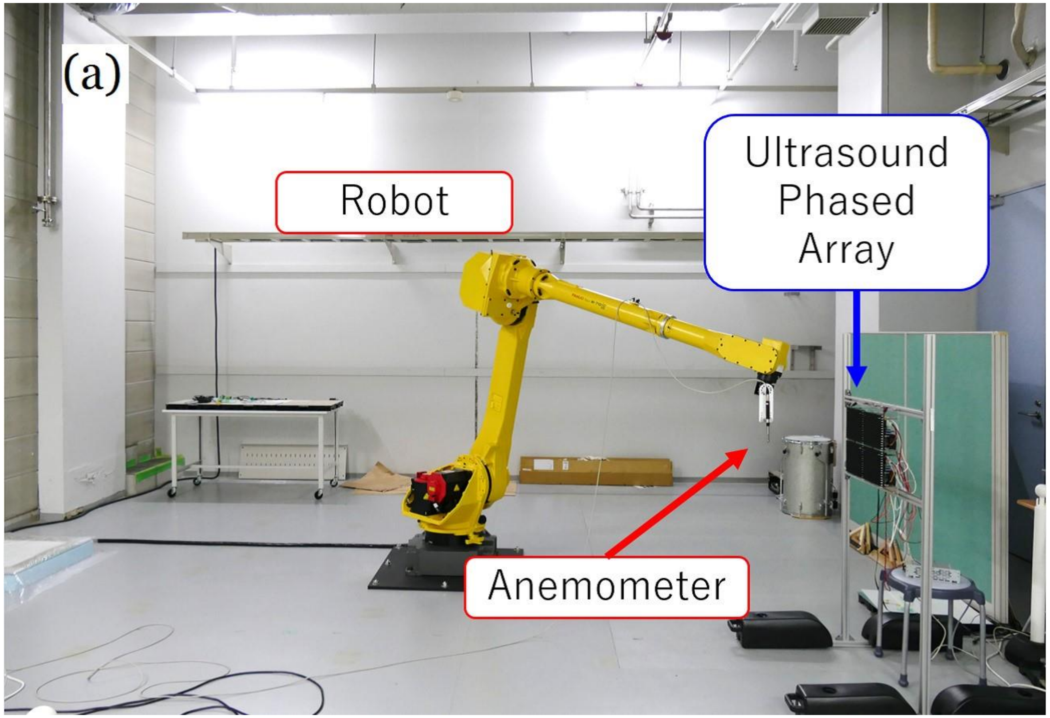


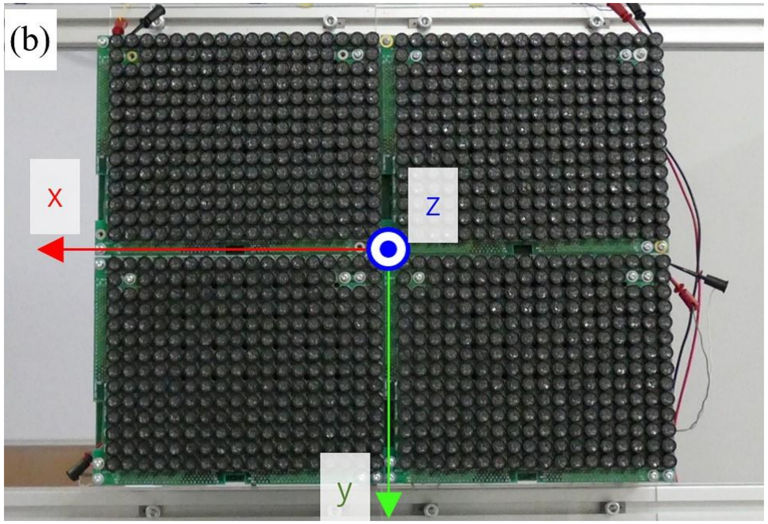


From Wikipedia

3D distribution of air stream velocity produced by ultrasound

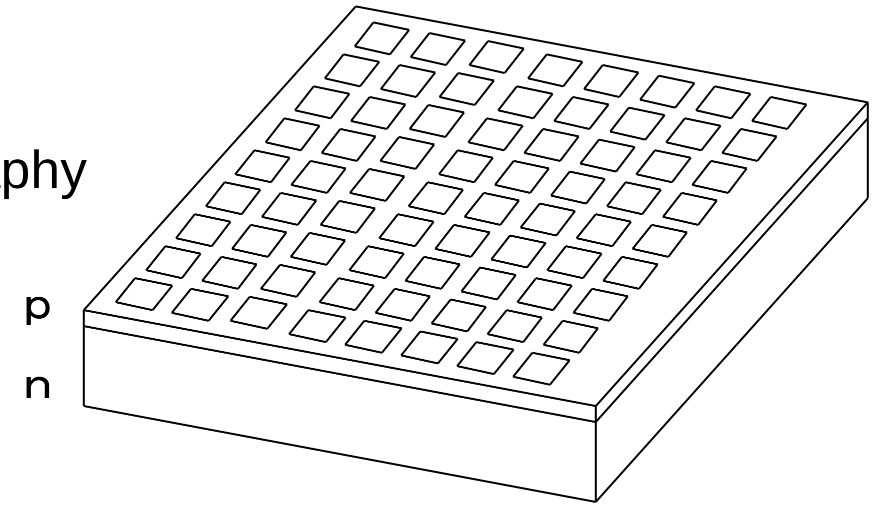



(a)
Robot
Ultrasound Phased Array
Anemometer


(b)
x
z
y

2. Array sensor

Integrated circuit by Photolithography



MOS Image Sensor

Problem: Thermal noise

Thermal noise by wire

$$\frac{Q^2}{2C} = \frac{kT}{2}$$

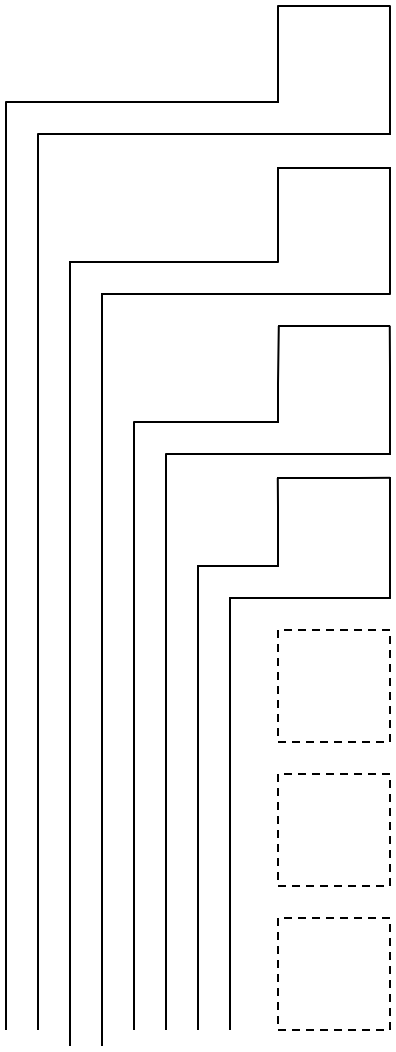
CCD
1970 Boyle & Smith
(Bell Laboratories)

CMOS Image sensor
（Each pixel has an amplifier）

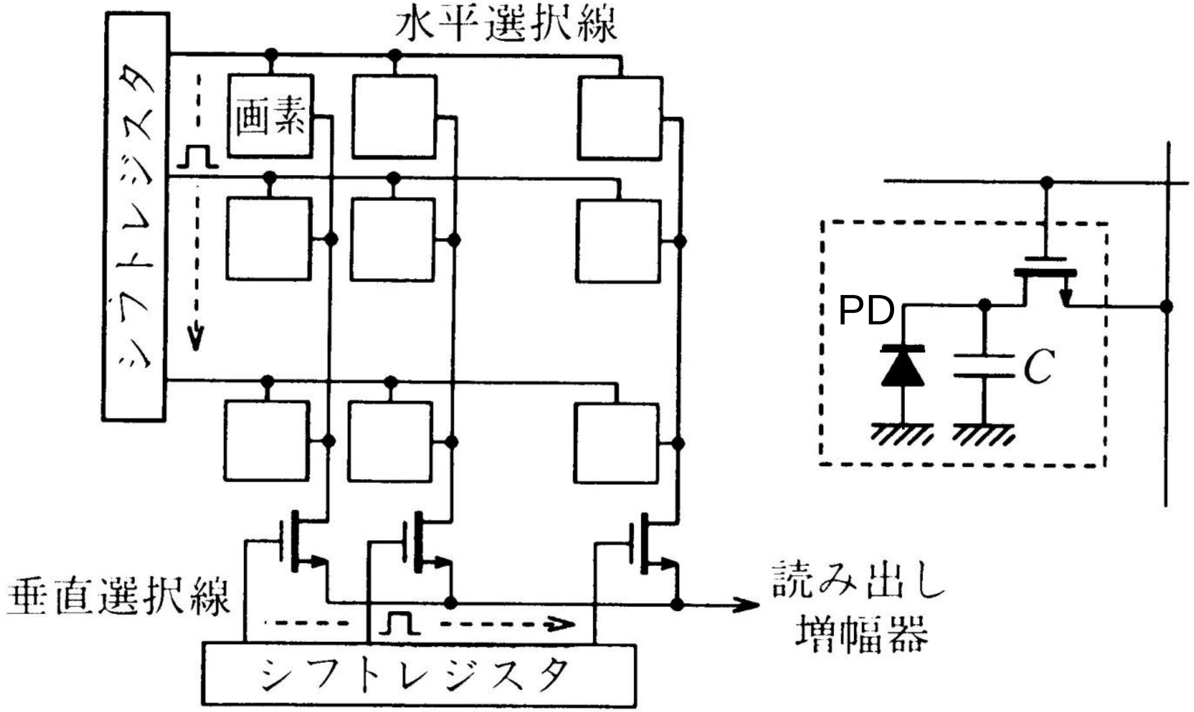
2. Array sensor

Wiring is a problem.

Wiring needs space!

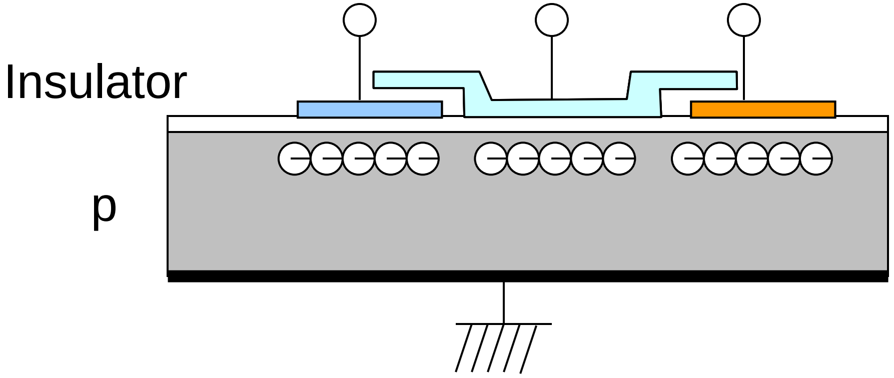


MOS Image sensor



(a) MOS 型撮像素子の構造

CCD --- Excluding wires



Principle

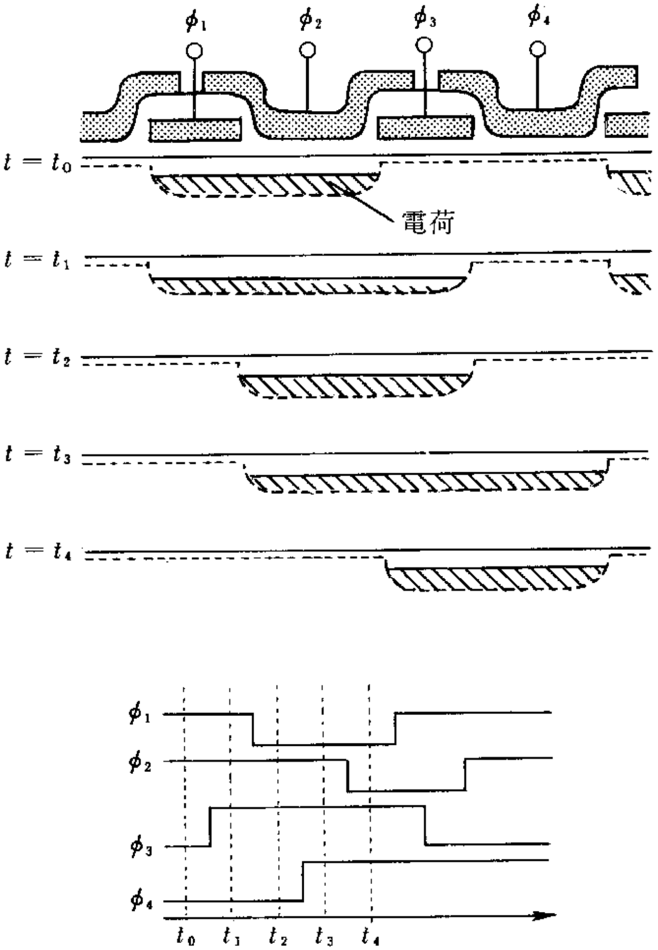
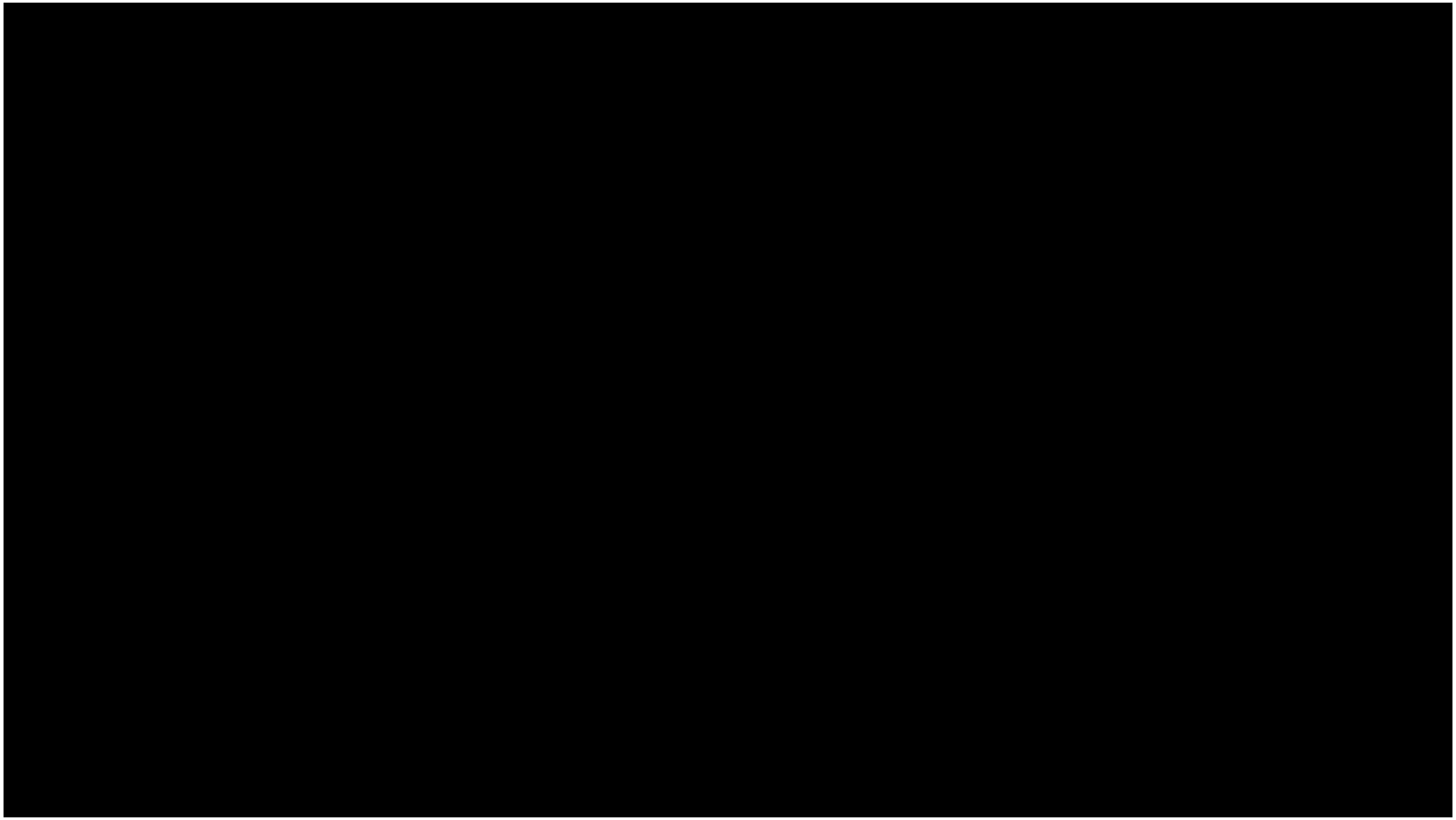


図 2　CCDの電荷転送機能

SONY α7S



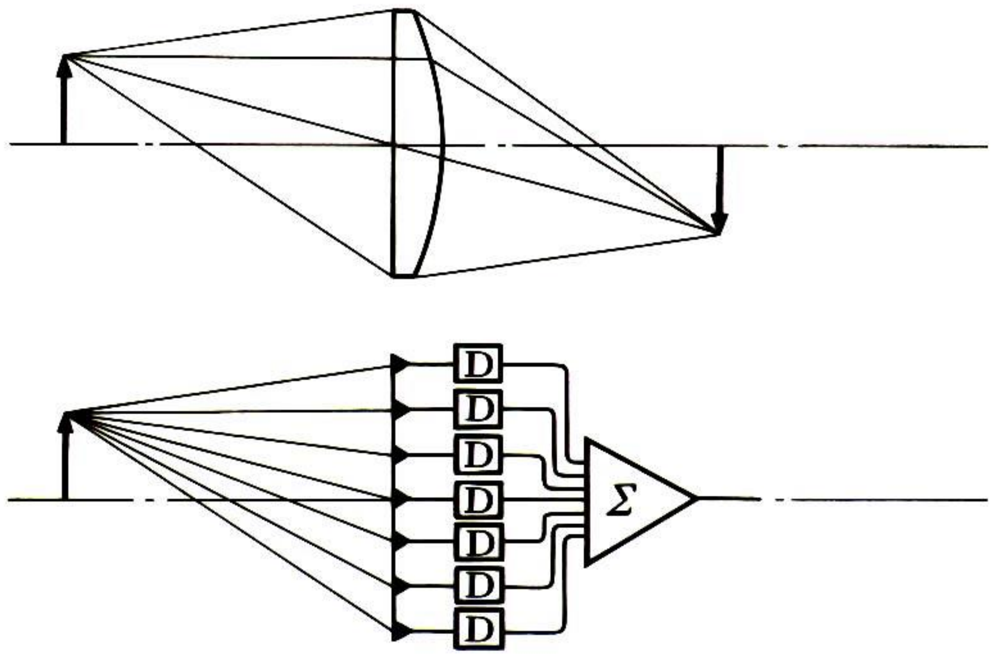
Energy of a single photon

λ = 500 nm（green light）: $hf = h\frac{c}{\lambda} = 3.97 \times 10^{-19}$ J

- What is the difference between scanning and array sensing in the measurement quality?

3 . Expansion of array sensing

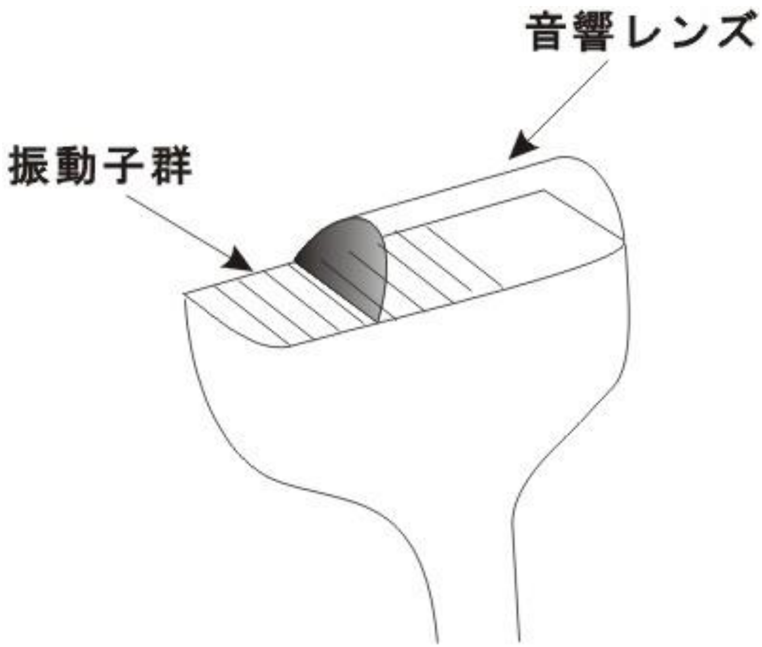
Synthetic aperture（Imaging without lens）

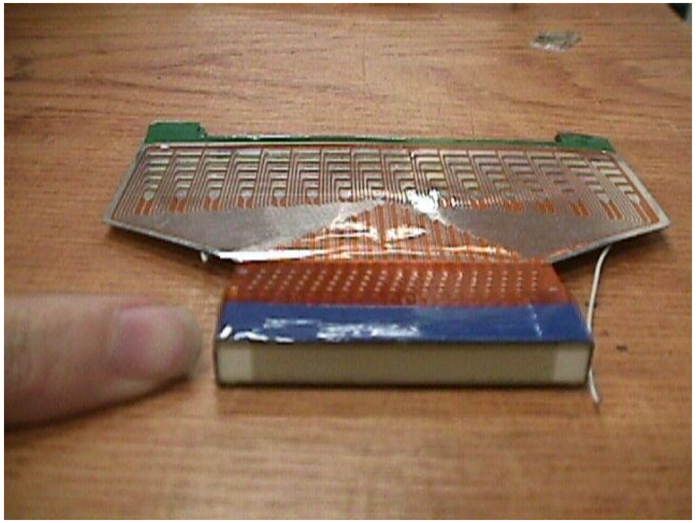


If you can measure the distribution of both the intensity and the phase on a plane, you don’t need a lens.

Synthetic Aperture Imaging

using ultrasonic phased array





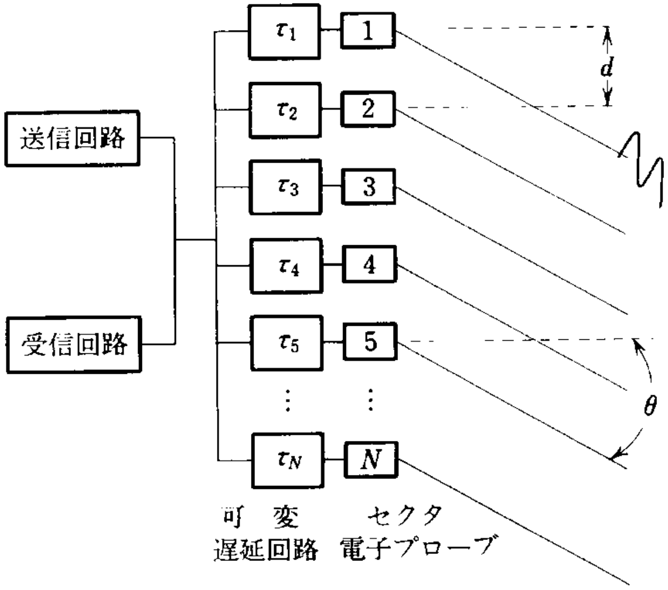
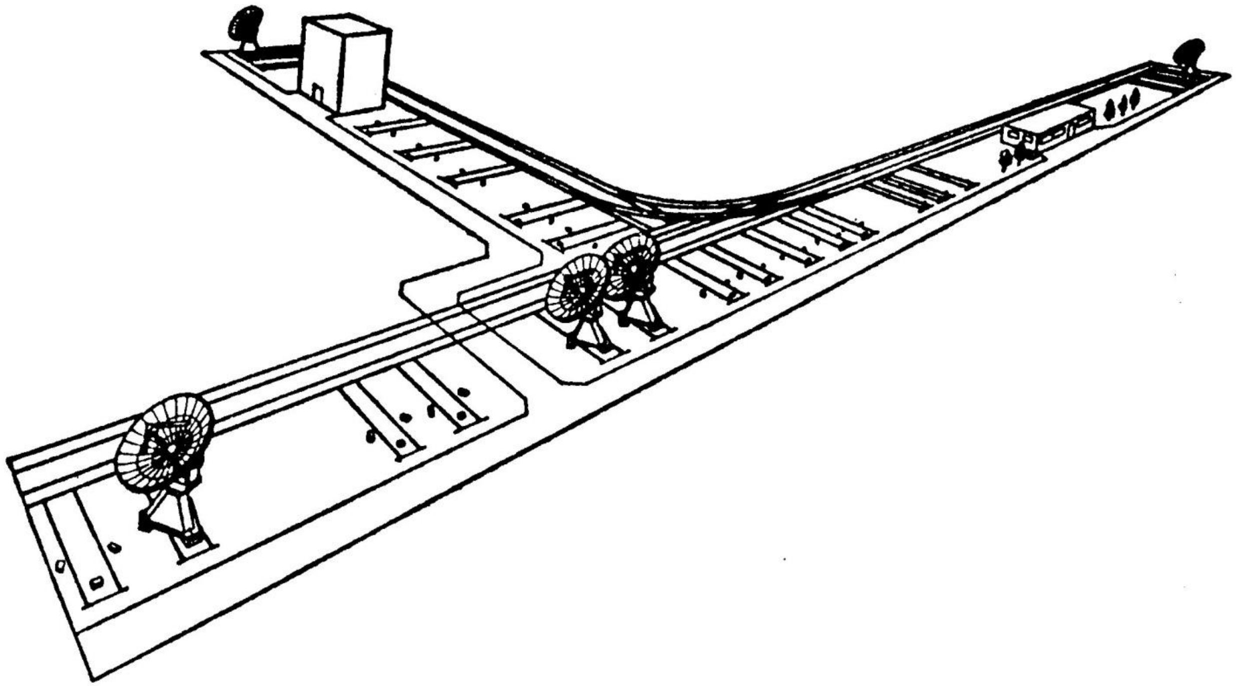


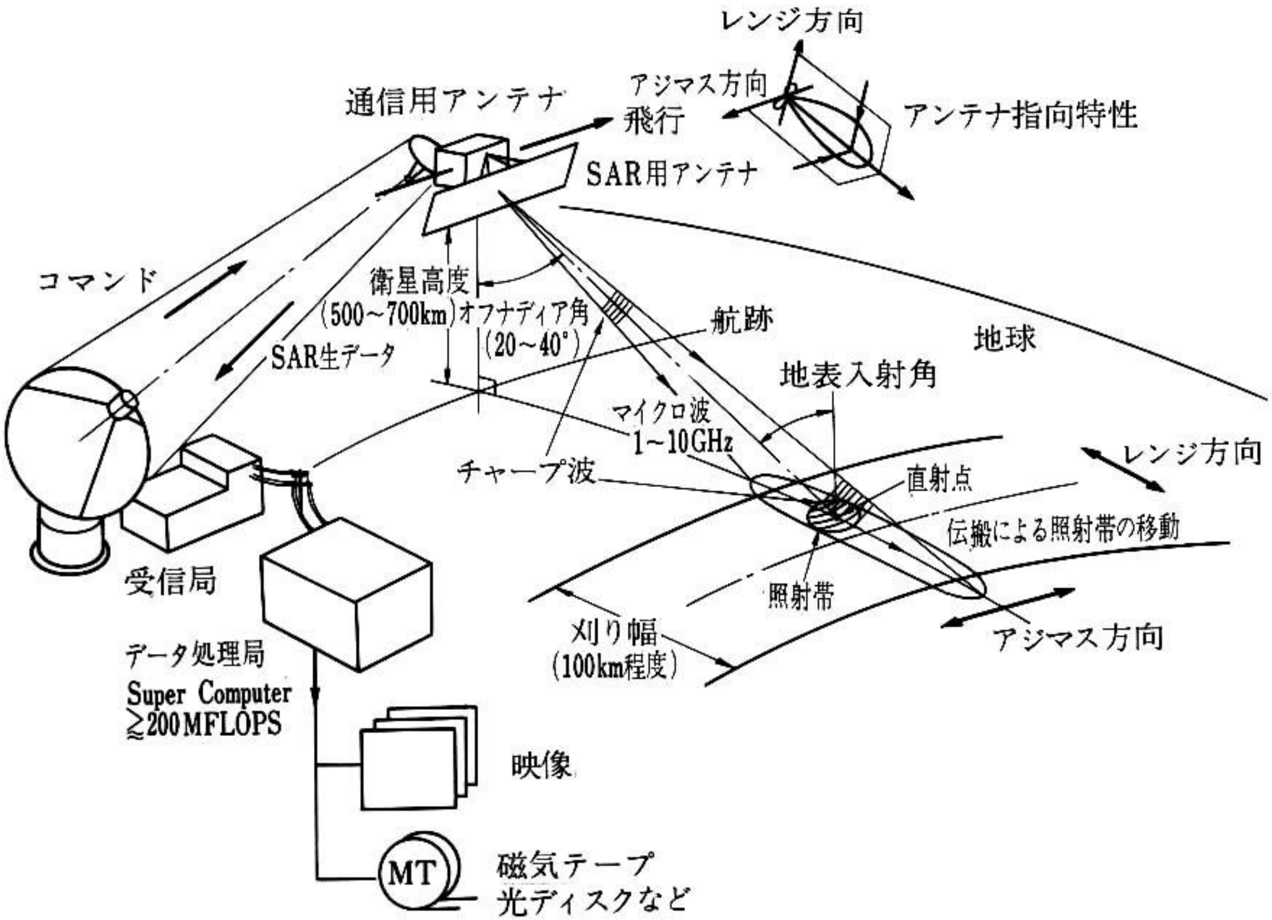
図 2.18 セクタ電子スキャンの原理

Synthetic Aperture

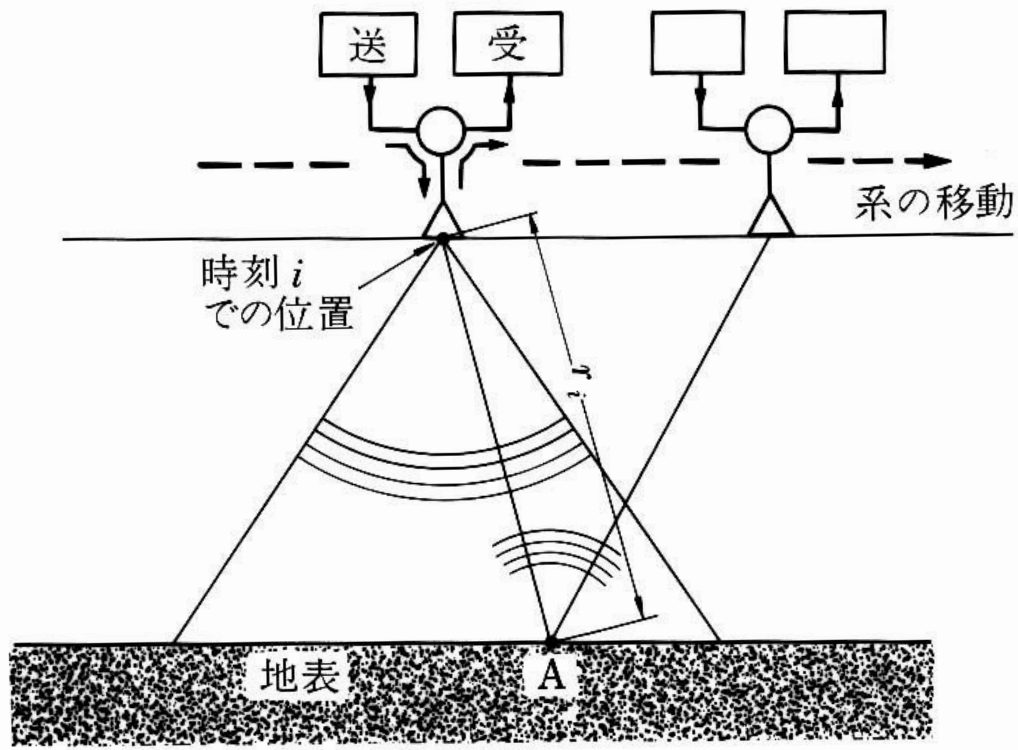


Synthetic aperture radio telescope (Nobeyama)

Satellite-Borne SAR (Synthetic Aperture Radar)



Synthetic Aperture



Signal emission and detection

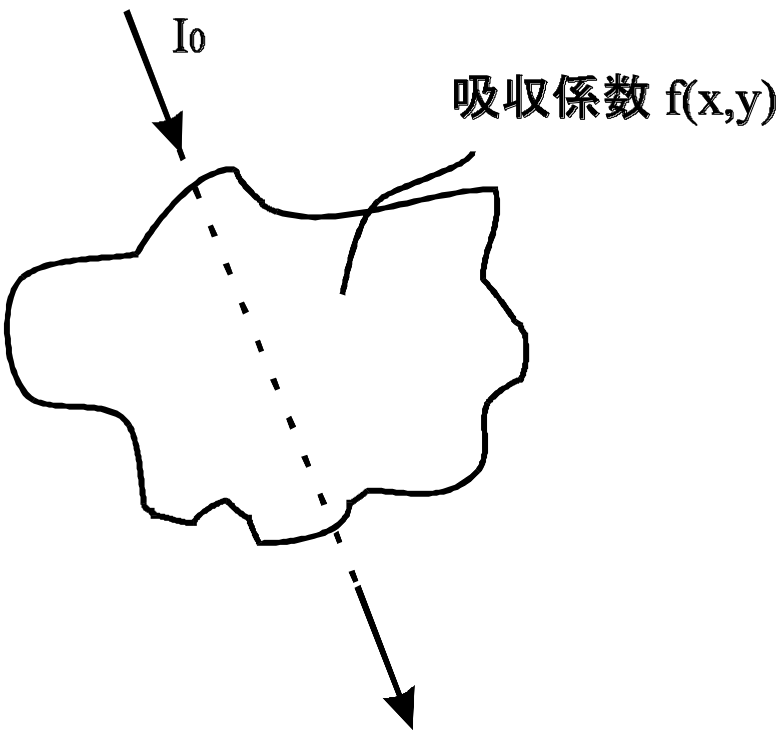
4． X-ray CT: Solving an inverse problem by calculation

Discovery of X-ray

Wilhelm Rentgen 1895

X-ray CT

I_0 : Incident X-ray intensity



I : Transmitted X-ray intensity

Attenuation of X-ray

$$I = I_0 \exp\left(-\int f ds\right)$$

therefore

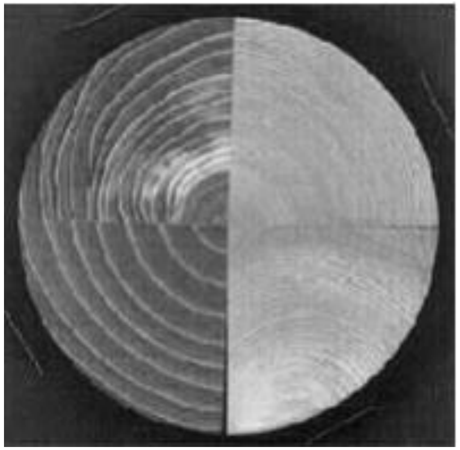
$$-\ln\left(\frac{I}{I_0}\right) = \int f ds$$

That is, the line integral of the absorption coefficients can be observed.

X-ray CT

X-ray photograph

CT Image (Human Head)



CT Image (Wood)

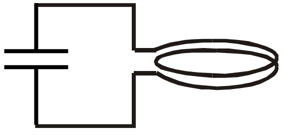
5. MRI　Localization by resonant frequency

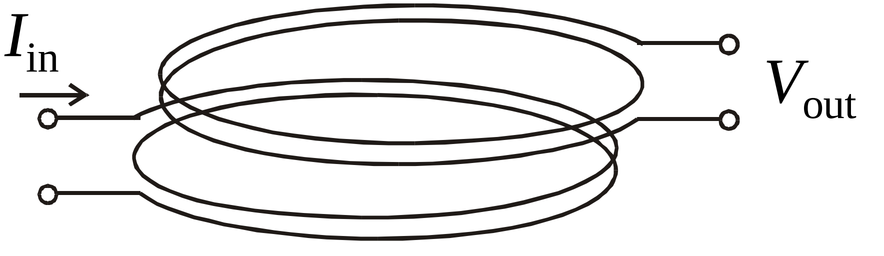
From NMR to MRI

NMR : Nuclear Magnetic Resonance
MRI : Magnetic Resonance Imaging

NMR of H ⟶ 42.58 MHz/T

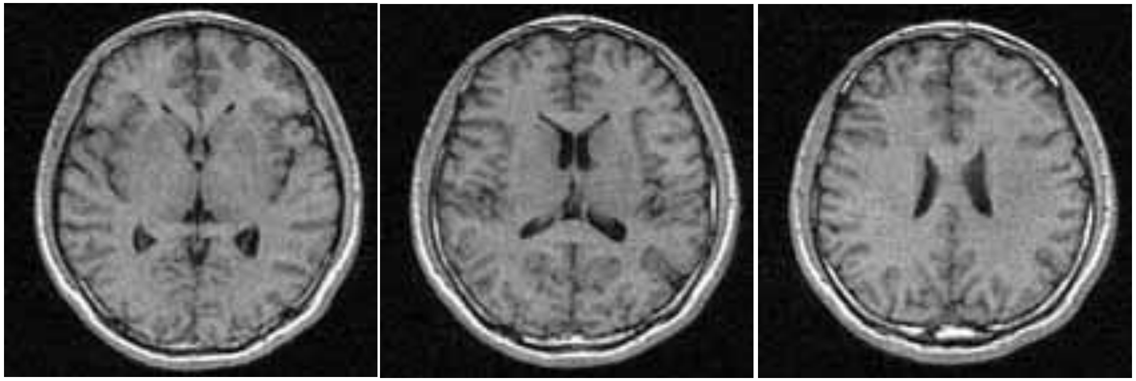
Conceptual model of NMR measurement using a LC resonator





MRI

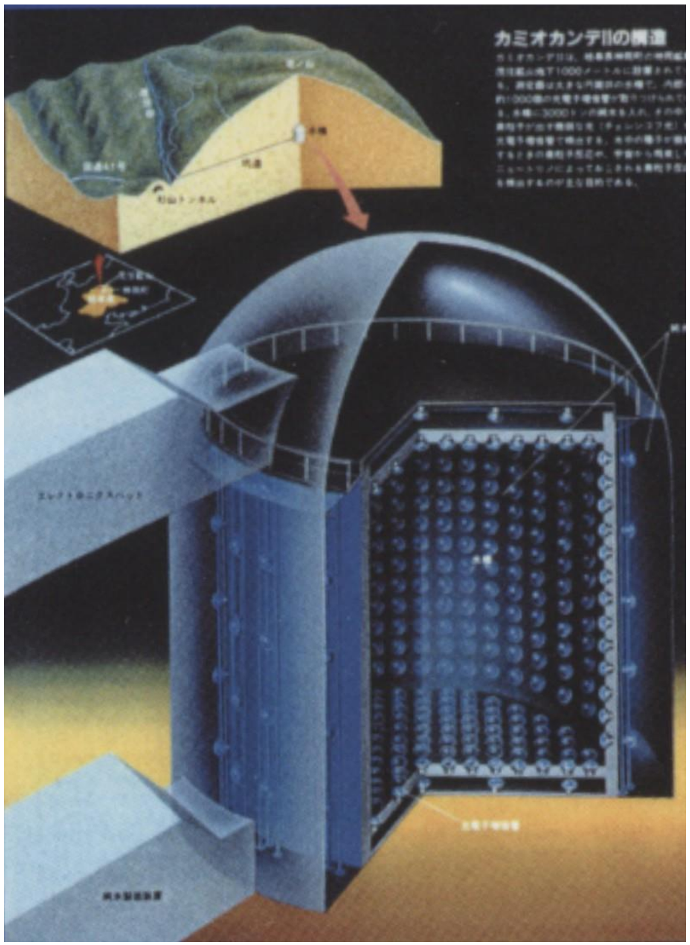
Imaging with gradient magnetic fields
Paul Lauterbur 1973

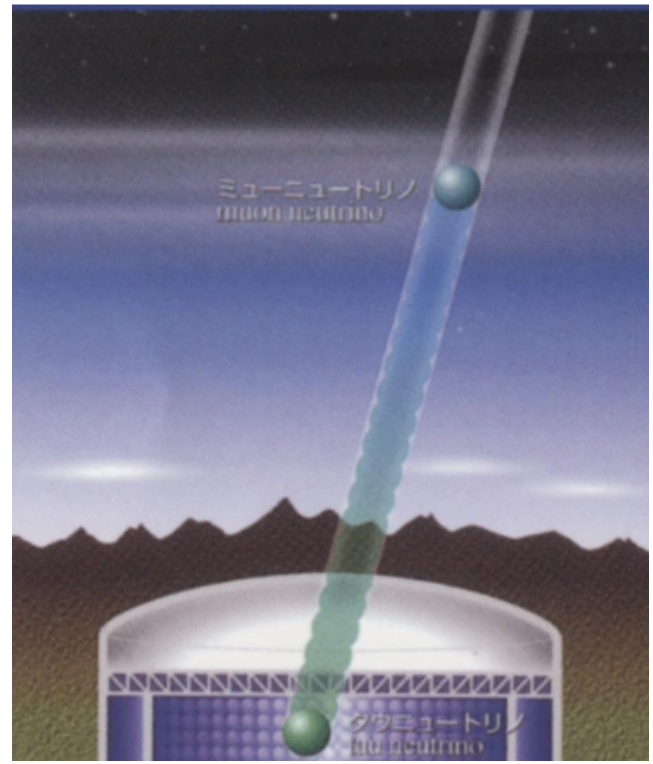


http://www.nips.ac.jp/smf/mri/mri-brain.html

６． Kamiokande --- Neutrino telescope

Estimating the motion directions of incoming neutrinos

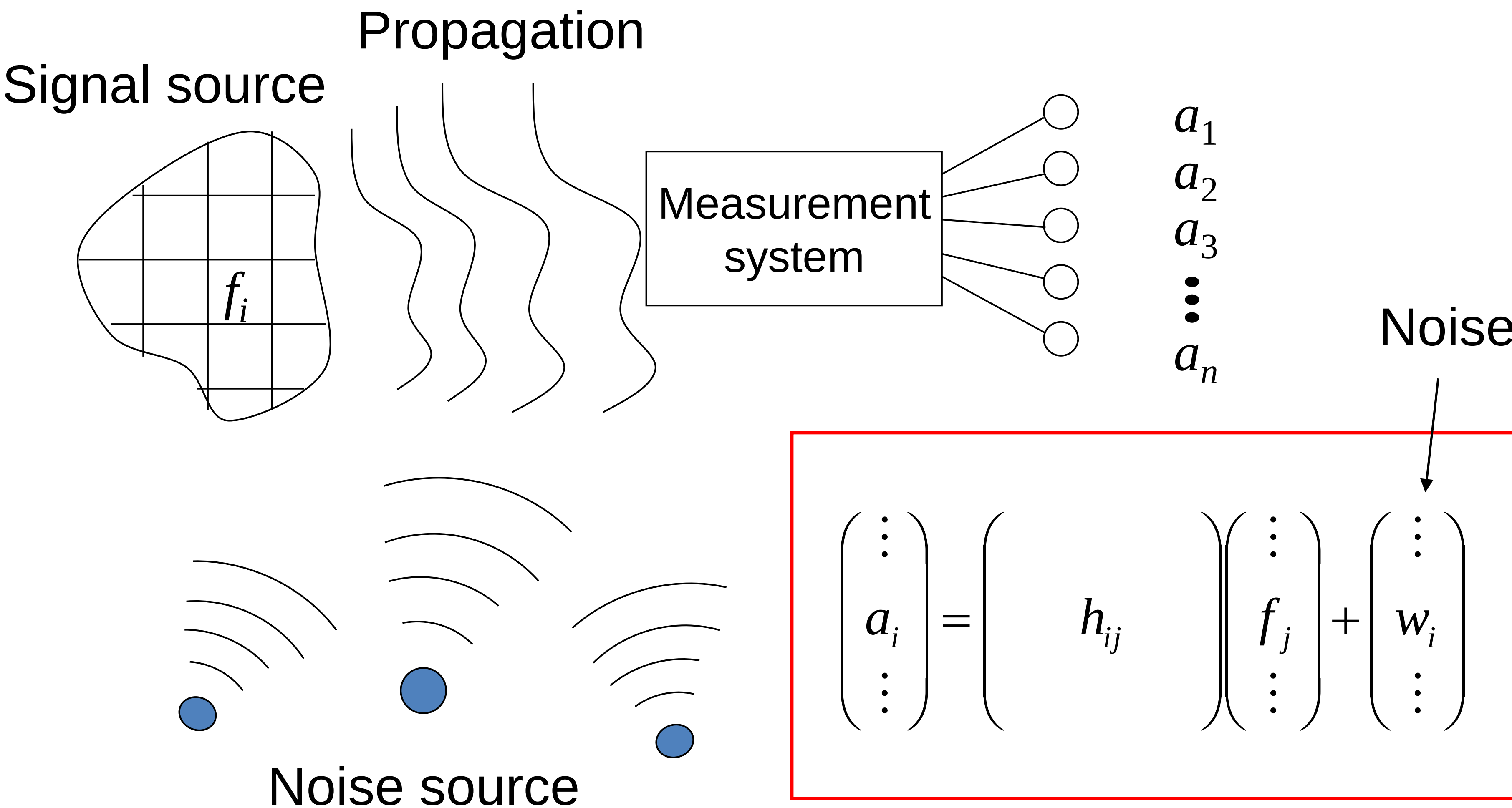




カミオカンデ 1983

Estimating the moving direction of charged particles by observing the shock waves (Čerenkov light)

Pattern measurement in a linear system



$$\begin{pmatrix} \vdots \\ a_i \\ \vdots \end{pmatrix} = \begin{pmatrix} & & \\ & h_{ij} & \\ & & \end{pmatrix} \begin{pmatrix} \vdots \\ f_j \\ \vdots \end{pmatrix} + \begin{pmatrix} \vdots \\ w_i \\ \vdots \end{pmatrix}$$

Estimate $\boldsymbol{f}$ from $\boldsymbol{a}$

(2) Pattern measurement today

- Development of MEMS
- Small, fast, and cheap IC
  → A sensor can transmit the measured value in digital data
- Big computational power
- Global network
- A sensor can measure its position and the time by itself
- Change of needs

The goal of the next class

Understanding a common method to address the following problem and applying it to actual problems

Estimating Q from a measured value vector

$$\mathbf{V} = (V_1, V_2, ..., V_n)$$

What is the best estimation under noise?
What is the best design of the measurement system to minimized the estimation error?