APPROACHES TO INTELLIGENT SENSORS

Hiro YAMASAKI Prof.

Faculty of Engineering The University of Tokyo
7-3-1, Hongo, Bunkyo-ku, Tokyo 113, Japan

Abstract

Sensing systems incorporated with dedicated signal processing functions are called intelligent sensors or smart sensors. The main objectives of the intelligent sensors are to realize new sensing functions and enhance design flexibility. The additional objectives are to reduce loads on central processing units and signal transmission channels by distributed information processing.

Technical approaches to the intelligent sensors can be divided into three different categories. Following are utilized as intelligence in the sensors:(1) New functional materials. (2) New functional structure. (3) Integration with computers.

Typical examples of the approaches are described. These are ranging from single chip sensing devices integrated with microprocessors to big sensor arrays utilizing synthetic aperture techniques, and from two dimensional functional materials to human sensory systems.

1. The Objectives of Intelligent Sensors

Various physical phenomena and effects can be applied for signal conversion in sensor devices. However some of their applications are limited by inherent nonlinearity or influential errors due to change in other quantities.

An accurate and flexible compensation of numerical signal processing can eliminate some of the constraint in present sensor techniques. Thus freedom of sensor design can be substantially enhanced. In other words, new sensor devices can be developed by the use of new phenomena which can not be utilized without numerical compensation or linearization. This is an advantage of intelligent sensors which can be realized at the early stage.1)

Physical quantities which are clearly described by mathematical models at a point can be measured accurately by the use of certain sensor device. However, identification of multi-dimensional state or images are difficult task for present sensing devices. Identification of complex state described multi-variables is also difficult. Especially diagnosis of facilities or fault detection of systems are urgent social needs for sensing techniques, but very few sensors can meet the requirement. A kind of intelligence is necessary for sensors to judge a certain state to be abnormal. However ordinary sensors do not have such intelligence.

Effective means to overcome above mentioned weak points of sensors are to develop sensing systems combining multiple sensors or arrays of sensors with computer aided measurement techniques. Intelligent sensors are one of powerful implementation of sensing systems with distributed functions of information processing.

As the result of the system approach and expanded design flexibility of device, new functions are realized. These are the most important objectives of intelligent sensors.

The second objective is to reduce concentrated loads of central processing unit and signal transmission channels by distributed information processing.

The first objective is especially important in the area of fault detection systems, remote sensings and multi dimensional measurement. The second one is important in applications relating to big systems such as space satellites.

2. Difficulties of Fault Detection

Why is the reliable fault detection sensor hard to realize? The most important reason is the lack of available machine criteria between normal and abnormal. The lack of the criteria is due to difficulties of model describing the fault or abnormalities. Normal state is described mathematically, but abnormalities can not be described easily. For example, how a fire of buildings is described physically? Can it be described only by temperature increase or existence of smoke?

3. Implementation of General Approaches to Intelligent Sensors

A general image of intelligent sensors seems to be one chip device in which sensor and microcomputer are integrated, but there are other different technical approaches to realize the intelligent sensors. The technical approaches can be divided into three categories as follows:

(1) New functional materials as intelligence.

(2) New functional structure as intelligence.

(3) Integration with computers.

4. Approach Through New Functional Materials

Main function of distributed signal processing is pre-processing for improvement of S/N ratio or selectivity of specified object. Characteristics of functional material can be utilized as intelligence of signal processing for signal discrimination.

One of important robotic sensors is tactile sensor, especially tactile imaging sensor. A sheet of conductive rubber and PVDF are useful as functional material for tactile sensors, a special algorithm is developed for recognition of object's shape and calculation of the center of force. 2)

Enzymes and microbes are very powerful to realize high selectivity for a specified substance , and they can minimize signal processing to reject the effects of coexisted components.

Extremely high selectivity even molecular discrimination can be realized by this approach.

Shape memory metals can make sensors·integrated with actuators. In addition to the integrated structure, their memory function may be useful for unique applications.

5. Approach Through Functional Mechanical Structure

If signal processing function is implemented in the mechanical structure or the form of sensors, processing of the signal is simplified and the rapid response can be expected.

Let us discuss a spatial filter for example, an object having a two dimensional optical pattern is projected through a spatial filter and its output light is focused on a photo sensor then converted into electrical signal.

The spatial filter samples a specific spatial frequency component out of all frequency components on the surface of the object. It also converts sampled spatial frequency component to temporal frequency components, which is proportional to object's velocity. Thus typical application of the spatial filter technique is noncontact velocity measurement with simple hardware.

We can tell three dimensional directions of sound sources with two ears. We can also identify the direction of sources even in the median plane.

The identification seems to be made based on the direction dependency of pinnae responses. Obtained impulse response are shown in Fig.1, in which signals are picked up by small electret microphone inserted in the external ear canal, and spark of electric discharge is used as the impulsive sound source. Differences can be easily observed. 3)

Usually at least three sensors are necessary for identification of three dimensional localization. So pinnae are supposed to act as a kind of signal processing hardware with inherent special shapes. We are studying on this mechanism utilizing synthesized sounds which are made by convolutions of impulse responses and natural sound and noise. 4)

Not only human ear systems, sensory systems of man and animals are good examples of intelligent sensing system with functional structure.

The most important feature of such intelligent sensing systems in integration of multiple functions; sensing and signal processing, sensing and actuation, signal processing and signal transmission.

Our fingers and eyes are typical example of integration of sensors and actuators. Signal processing for noise rejection such as lateral inhibition are carried out in the course of signal transmission in nervous system.

6. Approach Through Integration with Computer Part 1

The most popular image of intelligent sensor is an integrated device combining sensor with microcomputer, however, such sensors are not realized yet.

A development process of such intelligent sensors is illustrated in Fig.2. 5) Four separate functional blocks:sensor, signal conditioner, A/D converter and microprocessor are gradually integrated on single chip then turn into a direct coupling of sensor and microprocessor.

In my opinion, the present status seems to be the second stage in the figure. Let us discuss some examples in the stage.

Several results are reported about research on single chip pressure sensor device on which analog circuits for simple signal processing are integrated. 6)7) The circuits are amplifiers, temperature compensation circuit, oscillators etc.(Fig.3)

No results on signal silicon chip sensor device integrated with microprocessor is reported so far. A problem of insulation between circuits and sensors on a common silicon substrate is reported. The problem may limit the maximum range of signals. 8)

Usually sensors device should be exposed to severe environmental conditions, but microprocessor devices are relatively sensitive to ambient condition and electromagnetic noise induction. Reliability of processor in severe atmosphere may be another problem. However, in the case of noncontact measurement or image sensor, early realization will be possible.

Fig.4 shows a recent example of intelligent differential pressure transmitter for process instrumentation. A silicon diaphragm differential pressure sensor, an absolute pressure sensor and a temperature sensor are integrated on a single chip device. The output signals from these three sensors are applied to a microprocessor via A/D converter both on separate chip. The processor calculates the output and at the same time compensates effects of absolute pressure and ambient temperature numerically. The data for compensation of each sensor device is measured in the manufacturing process and loaded in ROM of the processor respectively. Thus the compensation can be very precise, the accuracy of 0.1% is obtained.

The transmitter has a pulse communication ability through two wire analog signal line and digital communication interface. Remote span and zero setting, remote diagnosis and other functions can be performed by the use of digital communication means.

The range of analog output signal is the IEC standard of 4-20mA DC, so total circuits including microprocessor should work within 4mA, the problem is overcome by CMOS circuit approach. 9)

Sensors having frequency output are advantageous in interfacing with microprocessors. Frequency output density sensor and pressure sensor which are compensated and linearized by dedicated processors are reported. 10)

A new approach to chemical intelligent sensors is proposed. Six thick film gas sensors which have different sensitivity for various gases are combined, and the sensitivity pattern is recognized by microcomputer. Materials of the sensors and sensed gases are shown in Table 1. Fig.5 shows several examples of sensor conductivity patterns for organic and inorganic gases. Typical patterns are memorized and identified by dedicated microprocessor utilizing similarity analysis of patterns. Maximum sensitivity of 1 ppm is reported. 11) 12)

7. Approach Through Integration with Computer Part 2

A more advanced function of coupled system of sensor and computer is observed in synthetic aperture sensing system.

The ultimate resolution of an optical system is determined by the ratio of its aperture size to the wave-length. As the wave-length of electromagnetic wave and ultra sonic wave are much longer than that of visible light, a big aperture of antenna or ultra sonic transducer is necessary. A radio telescope, for example, its aperture, the diameter of parabola antenna is required to be several tens of kilometers for similar resolution of optical one. Such big antenna can neither be built nor be driven, even if the design itself is possible.

The problem can be solved by the use of the synthetic aperture techniques. Array of small aperture sensors coupled with computer can be the substitution for array size aperture, and realize higher resolution.

Fig.6 shows the basic principle of synthetic aperture system corresponding to a dioptric system using optical lens. Each light from the object passes different path and with different time delay due to lens and then focus into the image. Each path seems to have different length, but all of them have the same propagation time.

In the synthetic aperture system, the outputs of each sensors to which different time lag is added are summed. The sum makes constructed image. Configuration of two systems seems quite different but their functions are same.

The direction of light axis and the focus of the synthetic aperture system can be driven by adjusting time delays in computer, so very rapid scanning is possible. Even simultaneous focusing into multi point is realizable if parallel signal processing is available. Such focusing function is never realized in physical systems.

This approach improves the resolution of radar and radio telescope substantially. Now we are working on the development of a high resolution sonar and a measuring system of velocity vector distribution in the sea water by the use of the synthetic aperture technique. The concept of our system and an example of computer simulation results are shown in Fig.7. 13)

This technique seems to be a very powerful approach for higher spatial resolution with small size point sensors which have poor resolution, thus it is an effective counter measure to overcome the weak point of present sensor techniques described previously.

8. Conclusion - Future Images of Intelligent Sensors -

Fig.8 shows a concept of an intelligent area image sensing system integrated on single chip device. Research of this device is planned in the R & D Project of Basic Technology for Future Industries which is promoted by MITI. A future image of intelligent sensors can be seen in the figure. 14)

The device has multi-layer structure. Each layer performs different function utilizing physical properties of layer materials. A number of light sensing devices are arrayed on the top layer, signal transmission devices are built in the second layer, memories are in the third, computing devices are in the fourth, and power supplies are in the bottom layer.

An image processing such as feature extraction and pattern recognition can be performed in the three-dimensional multifunctional structure. This is just like the retina of our eyes. As previously described in this paper, the important feature of sensing systems of man and animals is such integration of multi functions and distributed signal processing.

It can be said that a future image of our intelligent sensors are the sensing systems of man and advanced animals, in which the three approaches are combined together.

It is important to note that the approach to the future image is not single but three different approaches should be equally considered.

In this paper, these approaches are described with typical examples. At the same time, future progress of intelligent sensors are discussed.

References

1) W.G.Wolber:Smart sensors,ACTA IMEKO 1982,3 (1982).

2) M.Ishikawa & M.Shimojo:A Tactile sensor using pressure sensitive conductive rubber, Preprint 2nd Sensor Symposium 95 (1982).

3) Y.Hiranaka & H.Yamasaki:Envelope representations of pinna impulse responses relating to 3-dimensional localization of sound sources, J.Acoustical Society of America,73(1),291 (1983).

4) Y.Hiranaka et al:Envelope representation of pinna responses & localization trials by computer simulated sound, Note H-83-31, WG on auditory sense, Acoustical Society of Japan (1983).

5) Mackintosh International,Sensors, Vol.2 4 (1981).

6) S.Sugiyama et al:Integrated piezo resistive pressure sensor with both voltage & frequency output, Abstracts Solid state Transducer'83 115,(1983).

7) K.Yamada et al:A piezoresistive integrated pressure sensor, Abstracts Solid-state Transducer'83 113 (1983).

8) W.H.Ko et al:Capacitive pressure transducers with integrated circuits, Sensors & Actuators Vol.4 403 (1983).

9) Digital smart transmitter DSTJ 3000,J.SICE 22(12)1054 (1983)

10) I.Ohno:Frequency dependent sensors & their advantages, J.SICE 23(3)327 (1984).

11) M.Kaneyasu et al:Odor detection by integrated thick film gas sensor, Preprint of 22th SICE Meeting,271 (1983).

12) NE Report,Nikkei Electronics Sept.12(1983),78.

13) Y.Tamura & H.Yamasaki:Non-contact measurement of velocity vector distribution by numerical reconstruction of reflected sound field, Trans. SICE,18(1)44 (1982).

14) S.Kataoka:Sensors & human society, J.IEEJ 102(5)345 (1982).

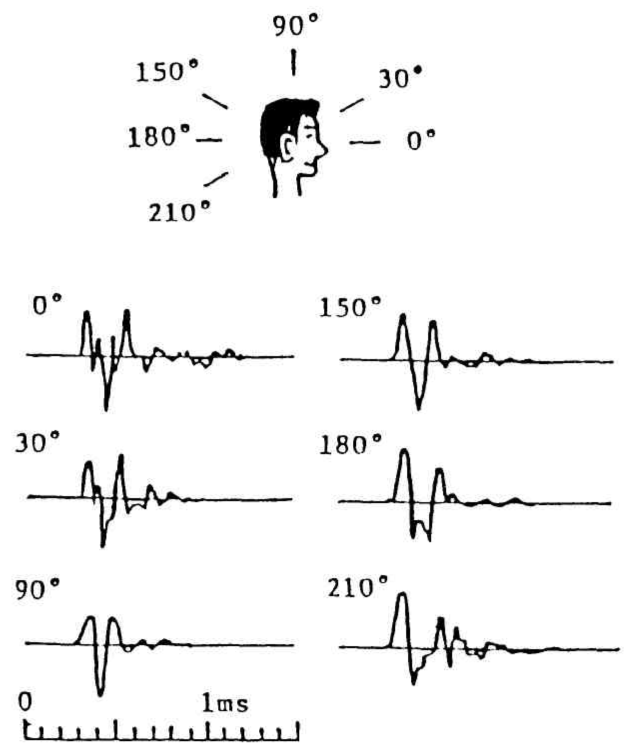


Fig. 1. Pinna impulse responses in the median plane.

Approaches to Intelligent Sensors

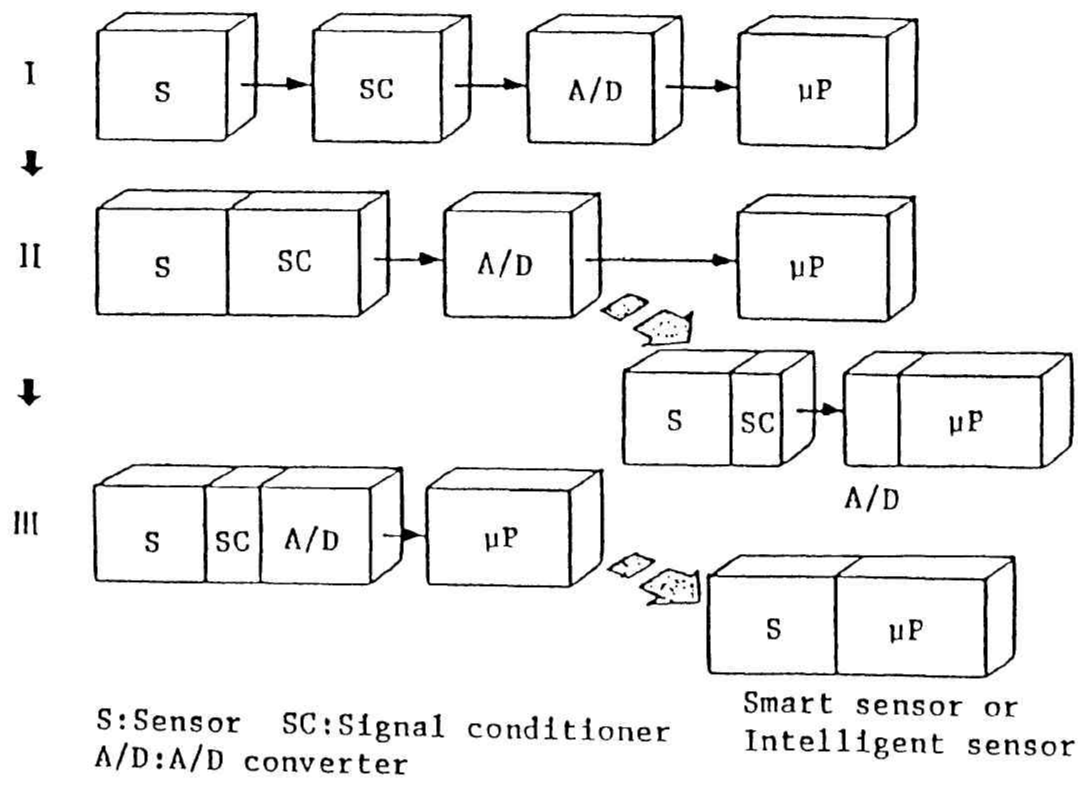


Fig. 2. Development trends in integration with microprocessors.

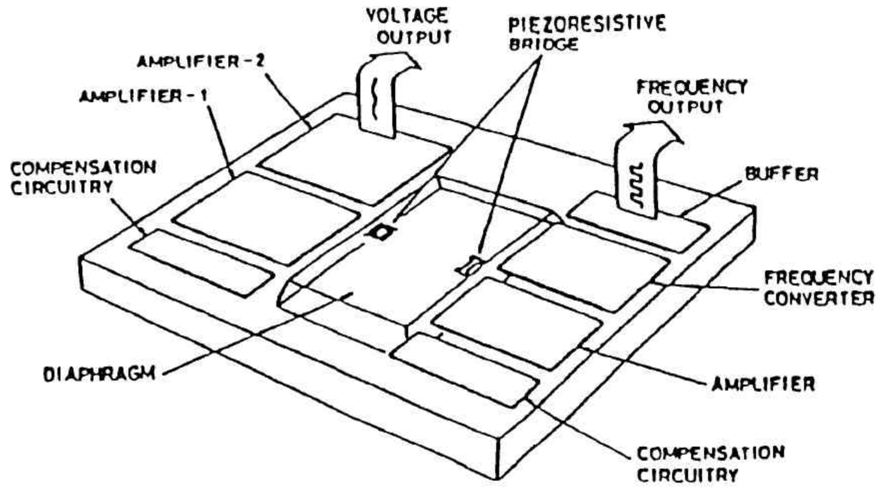


Fig. 3. Integrated pressure sensor with V & F output.

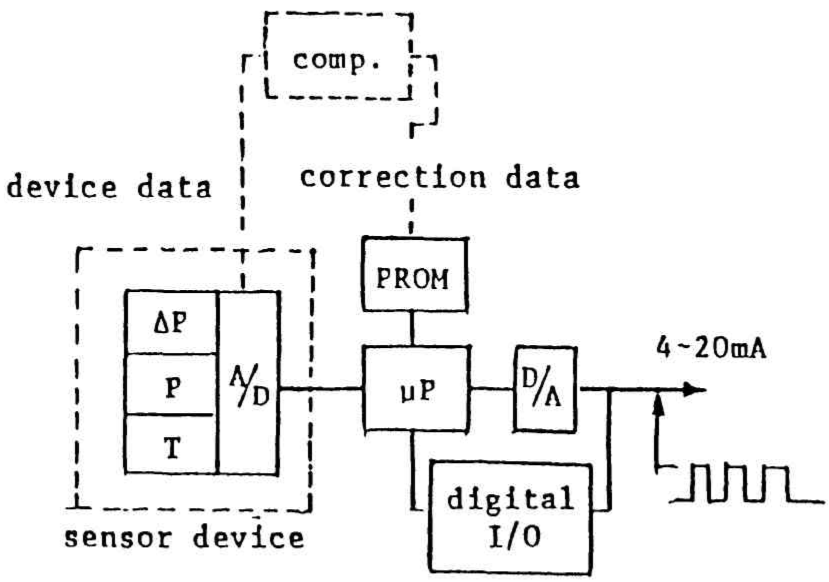
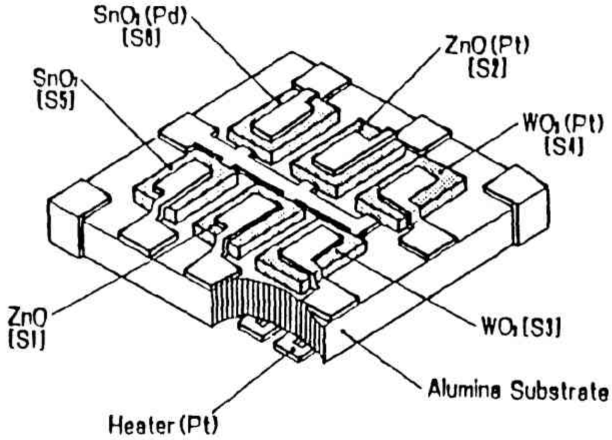


Fig. 4. Digital smart Δp transmitter.

Table 1. Materials & sensed gases of thick film gas sensors.

Sensor	Material	Sensible gas
S_1	ZnO	Organic gases
S_2	ZnO (Pt doped)	Same above (low Alcohol sensitivity)
S_3	WO_3	H_2, CO, C_2H_5OH
S_4	WO_3 (Pt doped)	Same above (low Alcohol sensitivity)
S_5	SnO_2	Reducing gases
S_6	SnO_2 (Pd doped)	Same above (high Methane sensitivity)



Schematic drawing of integrated sensor

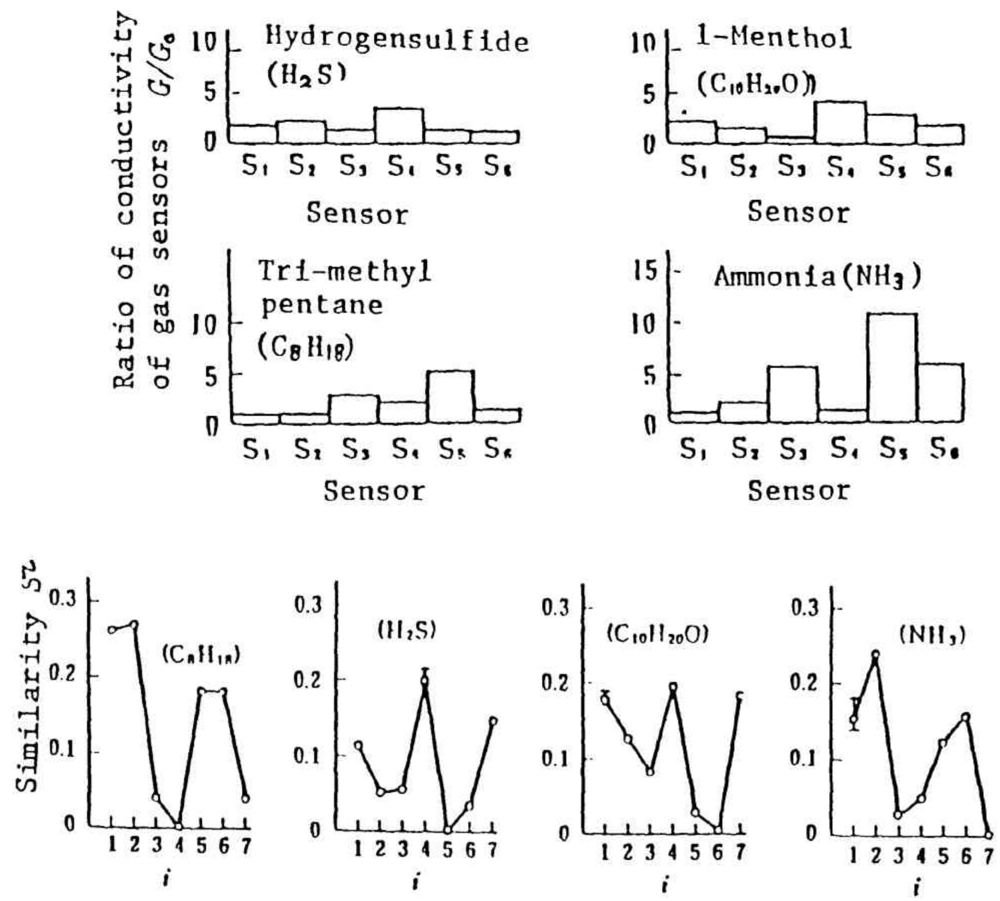


Fig. 5. Sensor sensitivity patterns for various gases.

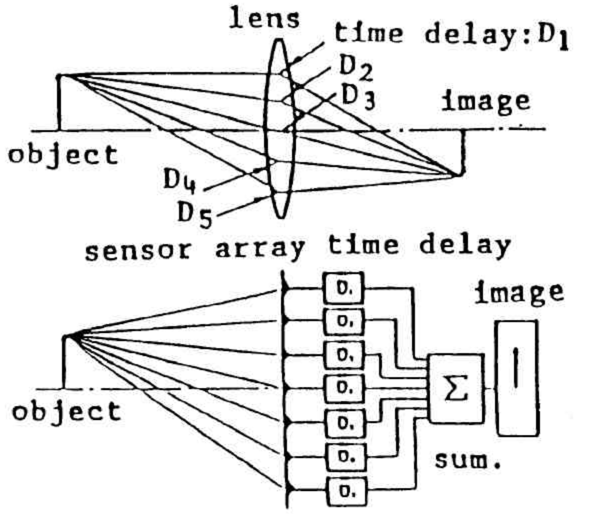


Fig. 6. Dioptric system using lens and synthetic aperture techniques

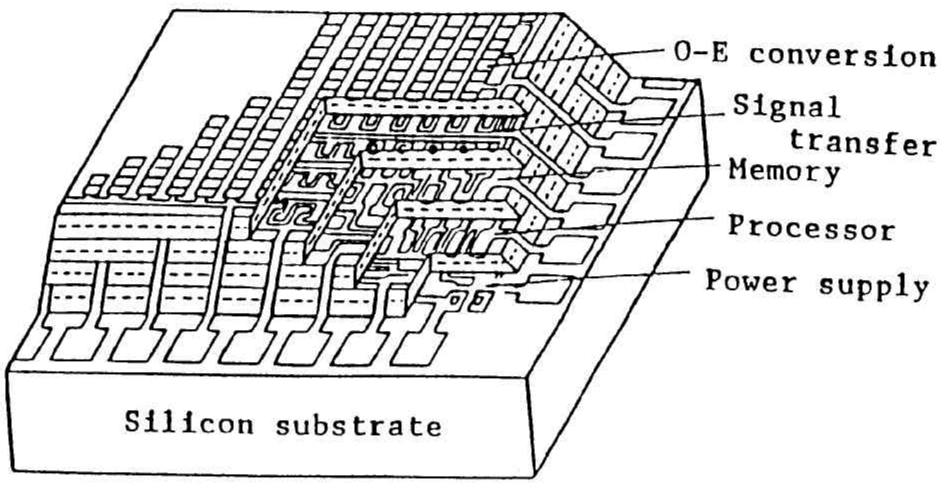


Fig. 8. Concept of integrated image sensing system with multi-layer structure.

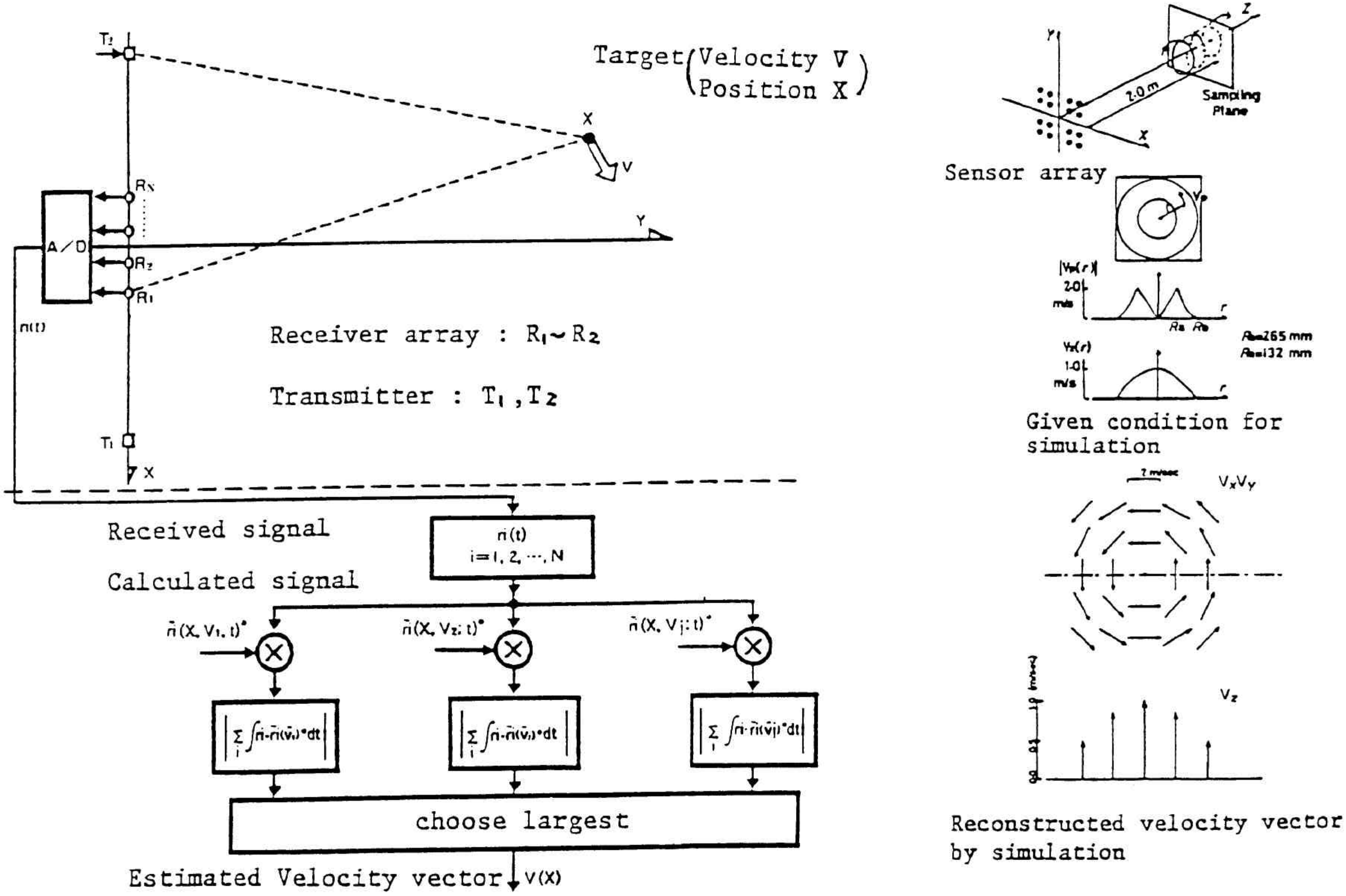


Fig. 7. Measuring system of velocity vector distribution utilizing synthetic aperture & numerical reconstruction of sound field. (left) Concept of the system, (right) A result of oomputer simulation.