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SENSOR TECHNOLOGY OF FUJI ELECTRIC

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1. PREFACE

In a word, sensors are generally said to replace the fifth sense of man and detect light, sound, odor, touch, temperature, etc. Actually, they also detect magnetism, infrared rays, ultrasonic waves, odorless gases, radiation, and other physical, chemical, and biological phenomena that cannot be sensed by man and are very effectively used in many fields from the standpoints of modern industrial growth and to make man's livelihood more abundant.

Sensors take use various principles and constructions depending on the objective. Recently, sensors designed to meet the strong demand of users for high performance, lower price, and smaller size are being practicalized by applying the results of research on new technology.

2. LATEST TREND OF SENSOR TECHNOLOGY

As a result of the growth of basic scientific technology and the accumulated result of the efforts of researchers engaged in sensor development, the sensing objectives are expanding and sensors are becoming smaller, more sensitive, faster, more stable, more reliable, simpler, safer, and cheaper.

Against this background, the technological trend is toward the micromachining, computerization, and the application of new materials and is outlined below.

2.1 Advance of micromachining technology and its application

The application of photolithography and etching, sputtering, ion implantation, chemical vapor deposition (CVD) and other semiconductor and IC fabrication technique to sensors is flourishing.

Small, light weight, fast response, low power consumption, high integration, and mass producible sensors have been achieved by means of this. A typical micromachining material is silicon. Silicon has many advantages as a Hall effect, piezo effect, and photoelectric effect material and dynamic quantity sensor by using its excellent mechanical properties such as the ability to integrate it with integrated circuits, etc. Examples of micromachining-applied sensors are small pressure sensor, power sensor, speed and acceleration sensor, ion sensitive field effect transistor (ISFET), color sensor, minute flow sensor, one dimension and two dimensions optical image element, infrared detection element, temperature sensor, and gas sensor.

When micromachining technology is applied, the size of each sensor can be minimized. Thus, it has many advantages such as the ability to form multiple elements having the same function as the optical image element of the above example on one chip, mount different sensors such as ISFET on one chip, perform processing on a chip by mounting a temperature sensor for temperature compensation on the same chip such as a silicon pressure sensor, simultaneously form peripheral circuits on the sensor chip, etc.

2.2 Intelligent sensors

In the past, sensors were conceived as devices which simply convert such sensing objectives as mechanical quantities, physical quantities, and chemical quantities to an analog electric signal and transmit this signal. However, the rapid advance of LSI semiconductor devices, including microprocessors, has made it possible to realize sensor signal processing and data storage functions easily and cheaply. Intelligent sensors have improved the sensor functions substantially and have also given birth to new sensors impossible to realized with conventional sensors through such elements and the integration and compounding of signal processing.

Thypical functions of these sensors are:

(1) Compensation of the amount of affect (for example, error causes) and improvement of linearity

(2) Addition of automatic calibration, self-check, and other independent functions

(3) Data analysis and statistical processing accompanying ultrahigh speed operation and data generation and processing matched to user needs

(4) Data exchange with high level system (computer) seen in digital (bidirectional) transmission from conventional analog transmission.

2.3 Application of new materials to sensors

Table 1 Typical materials and sensor device examples

Material	Sensor device example
Silicon and compound semiconductor	Magnetic sensor (Hall element) Power and pressure sensor (piezo element) Light sensor Infrared sensor Color sensor Radiation sensor Gas sensor
Ceramic	Power and pressure sensor Temperature sensor Oxygen sensor Infrared sensor SQUID type magnetic sensor
Optical fiber	Temperature sensor Electric field sensor Magnetic field sensor Angular speed sensor Speed sensor
Biological matter	Biosensor (oxygen sensor, microorganism sensor, immanization sensor)
High polymer	Temperature sensor Infrared sensor Power sensor Odor sensor

The development of new materials in recent years is having a large effect on the development of sensing technology and new sensors are being developed one after the other.

Typical materials and sensor device examples are shown in *Table 1.*

3. SENSOR MARKET

Fig. 1 shows the sensor production record (domestic) by measurement objective from 1984 to 1986 according to the Electronic Industry Review. The left side is the amount base and the right side is the quantity base. The amount increased sahaply from 1,713 hundred million yen in 1984 to 3,392 hundred million yen in 1986. Of this, the largest amount is the optical sensor 838 hundred million yen. The solid image element 417 hundred million yen, photoelectric effect and photoelectromotive effect optical sensor 309 hundred million, Hall effect magnetic sensor 139 hundred million, optical position and deviation sensor 148 hundred million, resistance change pressure sensor 164 hundred million, resistance change by temperature sensor 197 hundred million yen, and magnetic induction flow sensor 108 million hundred million yen are especially noticeable.

Fig. 2 shows the market share by application for the year 1986. It is seen that the quantity of consumer product use and general use sensors is high, but their unit cost low and, conversely, because of their nature, the peformance demanded of process use and safety use sensors is high and their unit cost is also high.

As can also be seen from these statistics, the importance of sensors for the purpose of measurement, control, and automation is increasing annually and the trend is toward continued expansion of the market.

Fig. 1 Mass production record of sensors by measurement objective

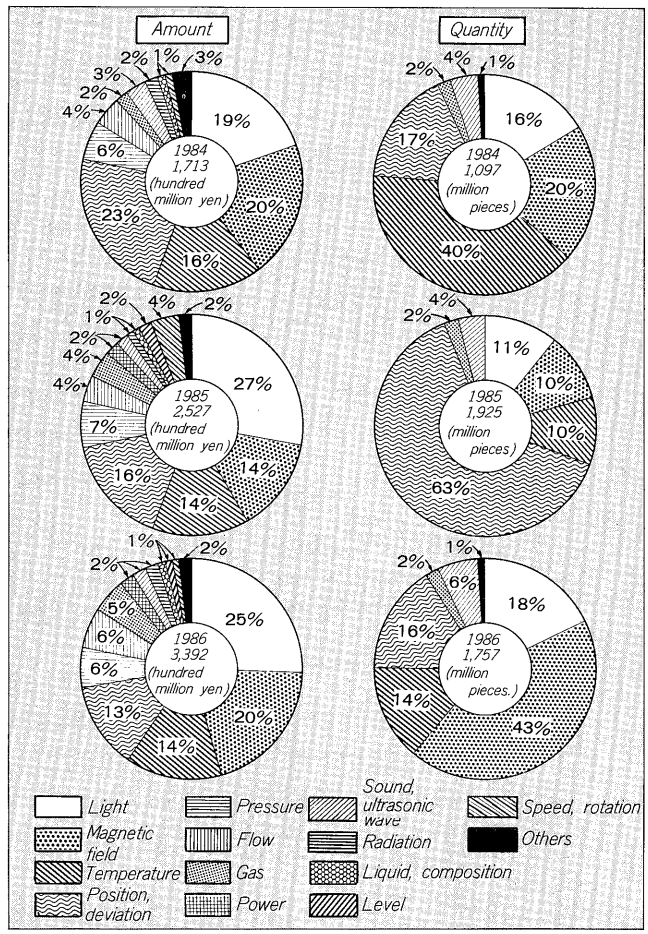
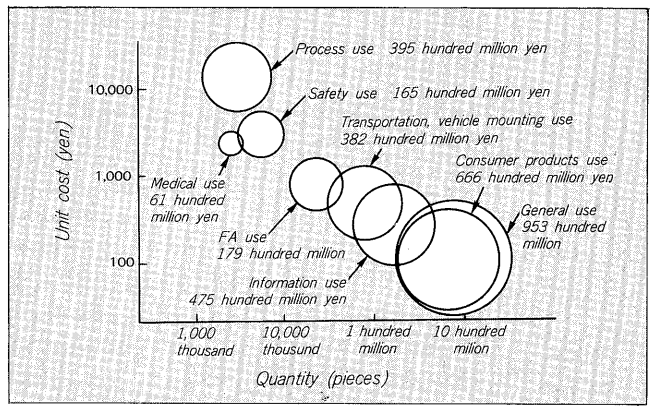


Fig. 2 Market share by sensor application



4. FUJI ELECTRIC SENSOR TECHNOLOGY

Fuji Electric sensor technology has a long history of almost 40 years. First, it was borne as sensors for temperature, pressure, flow, level, gas density, and other important measurement items at the creation of process automation. At the time, most sensors worked on mechanical or thermodynamic principles. They were also large and their per-

Table 2 Fuji Electric sensors

Sensing objective	Sensor, product name	Principle, element technology	Main specification, features	Main applications
Pressure, differential pressure	· Pressure, differential pressure transmitter · Pressure sensor	· Capacitance · Silicon piezo resistance effect	· Pressure: 0~10mmH_2O....500kg/cm² · Differential pressure: 0~10mmH_2O....30kg/cm² · Pressure: 0~0.4....8kg/cm²	· Process automation, factory automation general · Automotive, general industry
Flow	· Restrictor type flowmeter	· Sensing of the differential pressure before and after an orifice	· Diameter: 8A~	· Process automation general
	· Magnetic flowmeter	· Magnetic induction by Fanaday's law	· Conductive flow, 0~0.5m/s, diameter: 2.5A~	· Process automation general
	· Ultrasonic flowmeter	· Ultrasonic wave propagation speed flow dependency	· Liquid, −16m/s~+16m/s	· Process automation general
	· Karman vortex flowmeter	· Sensing of Karman vortex	· Normal temperature gas, diameter: 40A, 50A, 80A	· General industry
Temperature	· Temperature measuring resistor	· Platinum electric resistance change	· JIS, Pt 100Ω	· Factory automation, process automation general
	· Thermocouple thermometer	· Thermocouple electromotive force	· JIS, J, E, K, R PR thermocouples	· Factory automation, process automation general
	· Thermistor thremometer	· Thermistor resistance change		· Factory automation, process automation general
Humidity	· Lithium chloride hygrometer	· Lithium chloride absorption	· −10~30°C dew point	· Environment measurement, process automation general
	· Zirconia hygrometer	· Zirconia oxygen sensor application	· 0~30, 100vol %, up to 600°C	· Process automation general
Gas	· Magnetic oxygen analyzer	· Paramagnetism of oxygen gas	· 0~2....100vol %	· Process automation general
	· Heat conduction type analyzer	· Heat rays cooling effect by gas	· For example, 0~10vol % CO_2	· Process automation general
	· Zirconia oxygen analyzer	· Oxygen electromotive force of zirconia solid electrolyte	· 0~5....25vol % up to 60°C	· Process automation general
	· Oxygen sensor	· Electrolysis current of zirconia solid electrolytelyte	· 0~25vol %	· Environment measurement
	· Trace oxygen analyzer	· Phosphor light emission by oxygen	· 0~2....10ppm	· Process automation general
	· Infrared gas analyzer	· Infrared absorption spectral of various gases	· Various gases, 0~several ppm....100vol %	· Process automation, environment, pollution, research
	· Gas leak detector	· Contact combustion of combustible gas on catalyst	· LPG, iso-butane LEL level	· Home use
Water quality	· pH meter	· Glass electrode	· 0~14pH	· Process automation, home general
	· Infrared pollutant analyzer	· Infrared rays absorption spectral	· Light absorption: 0~0.5, 0~1	· Sewage treatment
	· Turbidity measuring instrument	· Light scattering	· 0~2ppm....1,000ppm	· Clear water and sewage treatment
	· Mixed liquor suspended solid measuring instrument	· Light scattering	· 500~5,000, 10,000ppm	· Sewage treatment
	· Residual chlorine analyzer	· Polarograph	· 0~1...6ppm	· Clear water and sewage treatment
	· Dissolved oxygen measuring instrument	· Diaphram galvanic cell	· 0~5, 15ppm	· Sewage treatment
	· Alkalinity measuring instrument	· Neutralization titration	· 0~50ppm/100ppm	· Clear water and sewage treatment
	· Ozone COD meter	· Pollutants are oxidized by ozone.	· COD: 0~20....1,000mg/e	· COD in sewage
	· Automatic total nitrogen measuring instrument	· Nitrogen compounds are oxidized by ozone and the infrared absorption spectral is measured.	· 0~70mg/ℓ	· Total nitrogen in sewage
	· Ammonia analyzer	· Ion electrode	· 0.1~1....100mg/ℓ	· Ammonia in sewage
	· Liquid conductivity measuring instrument	· Electric resistance	· 0~1....50μs/cm	· Boiler, pure water plant, waterworks
	· Particle counter	· Scattering of laser light	· Particles in pure water, sensing particle diameter: 0.1μm or greater	· Pure water plant, laboratory
Liquid organization	· Glucose analyzer	· Biosensor (immobilized enzyme electrode method)	· 0~150mg/ℓ	· Clinical testing, distillation process
	· Total acid, amino acid analyzer	· Titration using pH electrode	· Total acidity: 1~10, total amino acidity: 0.18~10	· Distillation process
	· Gas in oil analyzer	· Vacuum extrusion, gas chromatography	· Sensitivity: 1~10ppm	· Dissolved gas in transformer insulation oil
General organization	· Fourier transform infrared spectrometer	· Visible, infrared absorption spectral	· Gases, liquids, solids	· Laboratory automation general, quality control
Radiation	· Radiation monitor, radiation spectrometers	· Gas flow counter, GM tube, various sintillators ionization chamber, silicon semiconductor etc	· α-ray, β-ray, γ-ray, neutron ray, x-ray detection, various kinds from pocketable size to stationary type	· Atomic power facilities, hospital, laboratory
Thickness	· β-ray thickness meter	· β=ray absorption factor	· 2~6,000g/m²	· Metals, paper, etc, process automation general
	· γ-ray thickness meter	· γ-ray absorption factor	· 0~4mm....100mm	· Metals, process automation general
	· Infrared ray thickness meter	· Specific infrared ray absorption factor	· 10~2,000μm	· Plastic film
Level	· Float type level meter	· Position of float on liquid level sensed by induction potentiometer	· Water level: 0~0.5....40m	· Process automation general
	· Immersion type level meter	· Water pressure sensed by capacitance type or diffusion strain gauge type pressure gauge.	· Water level: 0~3....30m	· Process automation general
	· Ultrasonic level meter	· Ultrasonic wave reflection time	· Liquid, solid level: 0~3....30m	· Process automation general
	· b-ray level meter	· γ-ray transmission and absorption	· Liquid, molten metal level: 0~1....3m	· Process automation general
Position	· RF transmission proximity switch	· Electromagnetic induction	· Operating distance: 0.8....50mm	· Factory automation general
	· Magnetic proximity switch	· Electromagnetic induction	· Operating distance: 3.5....120mm	· Factory automation general
	· Ultrasonic switch	· Ultrasonic wave reflection	· Operating distance: 60....6,000mm	· Factory automation general
	· Photoelectric switch	· Interruption of light	· Operating distance: Sensing distance: 5....5000mm	· Factory automation general
	· Limit switch	· Mechanical contact	· Factory a	· Factory automation general
	· Photo microswitch	· LED	· Groove type groove width: 5mm Diffused reflection type sensing distance: 5mm	· Factory automation general
	· Rotary encoder	· Optical type	· 100....1,000 (ppr), waterproof type	· Factory automation general
Distance	· Oscillation type analog distance sensor	· Electromagnetic induction	· Operating distance: 0.4....10mm	· Factory automation general
	· Ultrasonic distance sensor	· Ultrasonic wave reflection time	· Operating distance: 200....1,000mm	· Factory automation general
	· Photoelectric distance sensor	· Triangular metering by LED and PSD	· Measurement range: 4~20mm	· Factory automation general
	· Automatic focusing IC	· Triangular metering using photosensor	· Proximity~infinity	· Automatic focusing camera use
Shape	· Bar code reader	· Light reflection	· Sensing distance: 180±25mm	· Factory automation general
	· Image sensor	· One dimensional CCD image sensor	· Number of bits: 2048, object present/absent, large/small pattern, length, coordinates judgement	· Inspection of medicine capsules
	· Capsule checker	· Image processing by two dimensional camera	· Outside shape, appearance judgement, processing capacity: 1,200 pcs/min	· Factory automation general
	· Multi window	· Image processing by two dimensional camera	· Shape, dimensions, appearance judgement, classification	· Factory automation general
	· Sight sensor module	· Image processing by two dimensional camera	· Shape, dimensions special sampling	· Factory automation general
	· Sight unit	· Image processing by two dimensional camera	· Kanji, Kana, numerics, alphabeted printed characters area operation	· Factory automation general
	· Optical character reader	· Image processing using adhesion type image sensor	· Kanji, Kana, numerics, alphabeted printed characters · 4,000 chars reading	· Factory automation general
Color	· Color mark sensor	· Combination of incandescent lamp and PD and optical filter	· Sensing distance 8~20m, minimum sensing width 0.1mm	· Factory automation general
Power	· Touch sensor	· Three directions, X, Y, and Z, measured by silicon strain gauge	· 9 element array/cm², 90 elements	· Robot hand touch
Vibration	· Small vibrometer	· Piezoelectric type acceleration sensor	· Small, lightweight, battery drive, 10~500Hz 1~399μm p-p	· Rotary machine vibration
Facilities abnormality	· Rotor health checker	· Motor load current analysis	· Sensing of rotor damage and unbalance during operation	· Motor diagnosis
	· Bearing nondisassembly analyzer	· Bearing vibration sensed by acceleration	· Sensing of bearing abnormality during operation	· Motor diagnosis
	· Rotary machine fuse blowing detection equipment	· LED and PD combination, optical fiber used	· Fiber length 115m	· Generator protection fuse diagnosis
	· Circuit breaker operating characteristics measuring instrument	· Control current, switching time, stroke characteristics are measured		· GIS high voltage circuit breaker diagnosis
	· GIS fault locator	· An optical fiber is used and scattered light is measured		· GIS internal change diagnosis
	· Oil level sensor	· Dial oil level meter with built-in potentiometer		· Transformer oil leakage detection
	· Wrapping tester	· Acoustic emission is sensed	· Wrapping position, strength evaluation	· Turbine rotor diagnosis
	· LTC switching torque sensor	· Twisting of output shaft of motor operator of tap switcher measured by strain gauge		· Transformer tap switcher preventive maintenance
	· Part discharge monitor	· Measurement of RF pulse component of grounded end		· GIS insulation accident preven prevention
	· Brush sparking sensor	· Sparking sensed by discharge electric wave		· Rotor diagnosis
	· Live wire insulation resistance monitor	· Resistance measurement		· Railway use wiring diagnosis
Others	· Surface particle sensor	· Scattering of laser beam	· Online measurement of particles of 0.5μm or larger	· Semiconductor production line, etc.
	· Car sensor for entrance automation of expressway	· Pressure sensitive rubber, photoelectric sensor	· Sensing of number of axles, classification of car outside shape	· Toll road toll collection

formance was also insufficient. These sensors have passed through many generations of changes and currently, new measuring sensors are realized through the application of new principles, computerization, and the use of new materials and new machining methods as described in paragraph 2. A typical sensor is the capacitance type pressure and differential pressure transmitter (FC series), which has a 10% share of market. In addition, the ultrasonic flowmeter, infrared gas analyzer, etc. are recognized as world products. Magnetic flowmeters, Karman vortex flowmeters, level meters, thermometers, water quality meters, gas analyzers, etc. are also available. We will steadily our power in the future. The optical fiber field instrumentation system (FFI) is the world's first system which uses an intelligent sensors and optical fiber field bus and is the direction of this field.

In 1965, the so-called high growth rate age of Japan, the pollution problem was examined close up and process use sensor technology was utilized and plant exhaust water analyzer, flowmeter, stack exhaust gas analyzer, automobile exhaust gas analyzer for labor environment measurement, and other sensors spread.

Instrumentation of clear water and sewage facilities was undertaken on a large scale from 1965 and various water flow, water pressure, water level, and water quality sensors were put into use in these facilities. The ultrasonic flowmeter, in particular, displayed its power in the measurement of the water flow and water level in large diameter pipes and open channels.

In accordance with the practicalization of the peaceful use of atomic power, the demand for radiation sensors and measurement systems for pollution by atomic power facility and research and medical radiation and environment monitoring from the standpoints of environmental safety and labor accident prevention and technology used in thickness sensors, etc. for special industrial measurement in the past was upgraded and expanded as products of this field.

The recent wave of total FA is having a large impact on sensors. In addition to mechanical to limit switches as nonproximity type switches, Fuji Electric has commercialized RF oscillation proximity switch, magnetic proximity switch, ultrasonic switch, photoelectric switch and photo microswitches as nonproximity switches, oscillation type analog distance sensor, ultrasonic distance sensor, and photoelectric distance sensor as distance sensors, color mark sensor as a color sensor, and an image sensor using a one-dimensional linear sensor. To meet the demand for FA, Fuji Electric is diversifying and serializing its types of sensors farther. The two-dimensional sensor has also built a leading position as distinctive technology of Fuji Electric. Greater sophistication and generalization are being pursued to meet steadily widening needs. Three-dimensional touch sensor research is being advanced as one link of a national project as a robot technique.

Sensor technology is also active in information machines, which have grown noticeably in recent years. An optical character reader (OCR) using an adhesion type image sensor was commercialized.

LPG and city gas leakage sensors for home use are supplied as public use sensors and in the field of sensors for installation use, silicon semiconductor pressure sensors are supplied as automobile engine air intake pressure sensors.

An automatic gas in oil analyzer, which analyzes the gas component in the insulation oil of large transformers, bearing nondisassembly diagnostic system, which senses rotary machine bearing abnormalities by means of a vibration sensor, small vibrometer, and many other sensors are practicalized as facilities abnormality diagnosis sensors.

A light-applied Fourier transform infrared spectrometer (FT-IR), water immersed particle counter, which counts the scattering of laser light by particles, particle monitor, etc. have been commercialized as experiment and research laboratory apparatus and inspection line apparatus. A glucose meter, which measures glucose density in clinical tests and the distillation process, etc. was also completed as biosensor-applied apparatus. Fuji Electric manufactures sensors spanning many fields, such as those described above. A table of Fuji Electric sensors classified by sensing objective is shown in *Table 2.*

Fuji Electric sensors and sensor-applied equipment were described above. As objective fields, sensors for the general process automation and factory automation and industrial fields based on the historical background of Fuji Electric and fields currently being undertaken are numerous, but other fields are also being tackled positively. Moreover, as technology, research and practicalization of electromagnetism application, light application, semiconductor application, ultrasonic wave application, ceramic application, bio and chemical application, and other sensor technology and systemization using these technology is being performed and our eyes are also fixed on new series.

5. CONCLUSION

Fuji Electric sensor technology was outlined. We intend to make efforts aimmed at the development of technology that meets the needs and the application of established technology to a wide range of fields. Your continued support and guidance is requested.