A Sensor Classification Scheme

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Abstract—We discuss a flexible and comprehensive categorizing scheme that is useful for describing and comparing sensors.

IN virtually every field of application we find sensors that transform real-world data into (usually) electrical form. Today many groups around the world are investigating advanced sensors capable of responding to a wide variety of measurands. In an attempt to facilitate comparing sensors and obtaining a comprehensive overview of them, we present here a scheme for categorizing sensors.

Sensor classification schemes range from the very simple to the complex. Extremes are the often-seen division into just three categories (physical, chemical, and biological) and the finely subdivided hierarchical categories used by abstracting journals. The scheme to be described here is flexible, intermediate in complexity, and suitable for use by individuals working with computer-based storage and retrieval systems. It is derived from a Hitachi Research Laboratory communication.

Tables I–VI, containing possible sensor characteristics, appear in order of degree of importance for the typical user. If we take for illustration a *surface acoustic-wave oscillator accelerometer*, these entries might be as follows: the *measurand*—acceleration; *technological aspects*—sensitivity in frequency shift per g of acceleration, short- and long-term stability in hertz per unit time, etc.; *detection means*—mechanical; *sensor conversion phenomena*—elastoelectric; *sensor materials*—the key material is likely an inorganic insulator; and *fields of application*—many, including automotive and other means of transportation; marine, military, and space; and scientific measurement.

Table I lists alphabetically most measurands for which sensors may be needed under the headings: acoustic, biological, chemical, electric, magnetic, mechanical, optical, radiation (particle), and thermal. A convention adopted to limit the number of Table I entries is that any entry may represent not only the measurand itself but also its temporal or spatial distribution. Thus, the entry "Amplitude" under the heading "Optical" could apply to a device that measures the intensity of steady infrared radiation at a point, a fast photodiode detecting time-varying optical flux, or a camera for visible light imaging.

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With a particular measurand, one is primarily interested in sensor characteristics such as sensitivity, selectivity, and speed of response. These are termed "technological aspects" and listed in Table II. Table III lists the detection means used in the sensor.

Tables IV and V are of interest primarily to technologists involved in sensor design and fabrication. Entries in Table IV are intended to indicate the *primary* phenomena used to convert the measurand into a form suitable for producing the sensor output. The entries under "Physical" are derived from the interactions among physical variables diagrammed in Fig. 1. This is a modification and simplification of the diagrams used by Nye [1] and Mason [2] to show binary relations among the common physical variables.

Most sensors contain a variety of materials (for example, almost all contain some metal). The entries in Table V should be understood to refer to the materials *chiefly* responsible for sensor operation. Finally, an alphabetical list of fields of application comprises Table VI.

Uses for the Classification Scheme

A useful scheme should facilitate comparing sensors, communicating with other workers about sensors, and keeping track of sensor progress and availability. Categorizing might help one think about new sensing principles that could be explored, and Table II might serve as a checklist to consult when considering commercial sensors.

All the entries in the tables have been given unique alphanumeric identifiers to facilitate use with computerized file systems such as electronic spreadsheets and databases used for storing information about sensors. The identifiers can be used as well in the keyword field of the lesser-known bibliographic utility *refer,* a part of the Unix operating system package, that enables a user to create and easily retrieve entries from a personalized database of citations to journal articles, books, and reports.

Sensor Examples

We consider several examples to illustrate how terms in the tables can be used to characterize sensors.

Diaphragm Pressure Sensor: Differential pressure distorts a thin silicon diaphragm in which the deflection is inferred from the change of the values of resistors diffused into the diaphragm. The measurand is pressure, A6.5; the primary detection means is mechanical, C5; the sensor conversion phenomenon (piezoresistance) is elastoelec-

TABLE I

A. MEASURANDS
- **A1. Acoustic**
  - A1.1 Wave amplitude, phase, polarization, spectrum
  - A1.2 Wave velocity
  - A1.3 Other (specify)
- **A2. Biological**
  - A2.1 Biomass (identities, concentrations, states)
  - A2.2 Other (specify)
- **A3. Chemical**
  - A3.1 Components (identities, concentrations, states)
  - A3.2 Other (specify)
- **A4. Electric**
  - A4.1 Charge, current
  - A4.2 Potential, potential difference
  - A4.3 Electric field (amplitude, phase, polarization, spectrum)
  - A4.4 Conductivity
  - A4.5 Permittivity
  - A4.6 Other (specify)
- **A5. Magnetic**
  - A5.1 Magnetic field (amplitude, phase, polarization, spectrum)
  - A5.2 Magnetic flux
  - A5.3 Permeability
  - A5.4 Other (specify)
- **A6. Mechanical**
  - A6.1 Position (linear, angular)
  - A6.2 Velocity
  - A6.3 Acceleration
  - A6.4 Force
  - A6.5 Stress, pressure
  - A6.6 Strain
  - A6.7 Mass, density
  - A6.8 Moment, torque
  - A6.9 Speed of flow, rate of mass transport
  - A6.10 Shape, roughness, orientation
  - A6.11 Stiffness, compliance
  - A6.12 Viscosity
  - A6.13 Crystallinity, structural integrity
  - A6.14 Other (specify)
- **A7. Optical**
  - A7.1 Wave amplitude, phase, polarization, spectrum
  - A7.2 Wave velocity
  - A7.3 Other (specify)
- **A8. Radiation**
  - A8.1 Type
  - A8.2 Energy
  - A8.3 Intensity
  - A8.4 Other (specify)
- **A9. Thermal**
  - A9.1 Temperature
  - A9.2 Flux
  - A9.3 Specific heat
  - A9.4 Thermal conductivity
  - A9.5 Other (specify)
- **A10. Other (specify)**

TABLE II

B. TECHNOLOGICAL ASPECTS OF SENSORS
- B1 Sensitivity
- B2 Measurand range
- B3 Stability (short-term, long-term)
- B4 Resolution
- B5 Selectivity
- B6 Speed of response
- B7 Ambient conditions allowed
- B8 Overload characteristics
- B9 Operating life
- B10 Output format
- B11 Cost, size, weight
- B12 Other (specify)

TABLE III

C. DETECTION MEANS USED IN SENSORS
- C1 Biological
- C2 Chemical
- C3 Electric, Magnetic, or Electromagnetic Wave
- C4 Heat, Temperature
- C5 Mechanical Displacement or Wave
- C6 Radioactivity, Radiation
- C7 Other (specify)

TABLE IV

D. SENSOR CONVERSION PHENOMENA
- D1. Biological
  - D1.1 Biochemical transformation
  - D1.2 Physical transformation
  - D1.3 Effect on test organism
  - D1.4 Spectroscopy
  - D1.5 Other (specify)
- D2. Chemical
  - D2.1 Chemical transformation
  - D2.2 Physical transformation
  - D2.3 Electrochemical process
  - D2.4 Spectroscopy
  - D2.5 Other (specify)
- D3. Physical
  - D3.1 Thermoelectric
  - D3.2 Photoelectric
  - D3.3 Photomagnetic
  - D3.4 Magnetoelectric
  - D3.5 Elastomagnetic
  - D3.6 Thermoelastic
  - D3.7 Elastoelectric
  - D3.8 Thermomagnetic
  - D3.9 Thermooptic
  - D3.10 Photoelastic
  - D3.11 Other (specify)

TABLE V

E. SENSOR MATERIALS
- E1 Inorganic
- E2 Organic
- E3 Conductor
- E4 Insulator
- E5 Semiconductor
- E6 Liquid, gas or plasma
- E7 Biological substance
- E8 Other (specify)

TABLE VI

F. FIELDS OF APPLICATION
- F1 Agriculture
- F2 Automotive
- F3 Civil engineering, construction
- F4 Distribution, commerce, finance
- F5 Domestic appliances
- F6 Energy, power
- F7 Environment, meteorology, security
- F8 Health, medicine
- F9 Information, telecommunications
- F10 Manufacturing
- F11 Marine
- F12 Military
- F13 Scientific measurement
- F14 Space
- F15 Transportation (excluding automotive)
- F16 Other (specify)

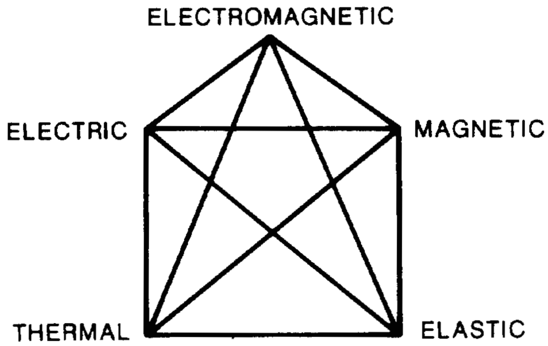

Fig. 1. Physical phenomena represented by lines connecting nodes that represent physical fields.

tric, D3.7; and the key sensor material is an inorganic semiconductor, E1 and E5.

SAW Vapor Sensor: A polymethylmethacrylate (PMMA) polymer coating in the propagation path of a surface acoustic wave delay-line oscillator absorbs vapor, causing mass loading and hence a change of wave velocity and oscillator frequency. The measurand is chemical concentration, A3.1; the primary detection means is mechanical, C5; the sensor conversion phenomenon is physical transformation (a vapor becomes an absorbed constituent), D2.2; and the key sensor material is the organic polymer, E2. If, for greater selectivity, the polymer were altered so that it reacted chemically with only one type of vapor, chemical transformation, D2.1, would be the primary conversion phenomenon. If the polymer were replaced with an immobilized antibody to detect a particular antigen, biochemical transformation would be involved, D1.1.

Fiber Optic Magnetic Field Probe: A magnetostrictive nickel film deposited on an optical fiber in an interferometer is distorted by an external magnetic field, causing a photoelectrically detected change of light level at the interferometer. The primary detection means is mechanical, C5, and secondarily electromagnetic waves are involved, C3. The fundamental conversion phenomenon is elastomagnetic, D3.5, involving primarily a metallic film, E3, and an insulating fiber, E4. Since fiber optic sensors constitute an important identifiable class, one might key all such sensors similarly, for example by specifying under "Other" in "Detection Means" a category "C7.1 fiber-optic."

Acknowledgment

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References

[1] J. F. Nye, *Physical Properties of Crystals.* Oxford: Oxford Univ., 1957.

[2] W. P. Mason, *Crystal Physics of Interaction Processes.* New York: Academic. 1966, see Figs. 1.1 and 1.2.

Richard M. White (M'63-F'72), for a photograph and biography please see page 123 of the March issue of this TRANSACTIONS.

This node-level classification scheme provides a satisfactory classification rate, 94.10%, with little resources. Finally, a confidence-based fusion algorithm improves the overall accuracy by fusing the information among sensor nodes. Our experimental results show that the proposed group-level fusion algorithm improves the accuracy by an average of 4.17% accuracy with randomly selected nodes. Keywords. Sensor network Target classification Sensor fusion Gaussian mixture model (GMM) Classification and regression tree (CART). This is a preview of subscription content, log in to check access. Note A sensor. classification scheme based on the frequency spectrum. behavior is presented. I. INTRODUCTION. n practice the robotic manipulators present some degree of. unwanted vibrations. In fact, the advent of lightweight. arm manipulators, mainly in the aerospace industry, where.Â A new sensor classification. scheme was proposed. The adopted methodology leads to. arrange the robotic signals in terms of identical spectrum. behavior, obtaining three groups of signals. This observation. merits a deeper investigation as it gives rise to new valuable. results to instrument control applications.