Ontological Knowledge Base of Physical and Technical Effects for Conceptual Design of Sensors

V M Zaripova and I Yu Petrova

Department of CAD Systems, State Autonomous Educational Institution of Astrakhan Region of Higher Professional Education “ASTRAKHAN CIVIL ENGINEERING INSTITUTE”, Astrakhan, Russia

E-mail: vtempus2@gmail.com

Abstract. This article discusses design of the knowledge base of physical phenomena based on domain-specific ontology. Classification of various physical phenomena in the knowledge base is based on energy-information model of circuits (EIMC) suggested by the authors. This model is specially aimed at design of new operating principles of sensing elements (sensors). Such a knowledge base can be used to train intended engineers, specialists in sensors design.

1. Introduction

According to many researchers the global market of sensors annually increases by 7-9%. And the number of physical phenomena and processes applied in sensor design is growing rapidly. But different physical properties that are the basis of sensor operation principle are described through the physical and mathematical tools corresponding to the given phenomena class only. This impedes automation of the design process, increases the period of new sensor development and their cost. This is why it is critical to use an automated data retrieval system, intended for centralized data collection of physical effects, to design the sensor operation principle and train engineers

A number of methods of conceptual design based on the knowledge bases of physical effects and phenomena are well known. For example:

1) Theory of Inventive Problem-Solving - TRIZ or TIPS), the author is Altshuller (Russia) [1],[2];
2) Systematic approach to design engineering, authors are Pahl и Beitz (Germany) [3];
3) Method of conceptual design, the author is Koller (Germany) [4].

All these methods are based on classified knowledge of physical effects. But all of them are aimed at support of conceptual design of any technical devices regardless of the sphere of its application. Physical effects in the knowledge bases of these systems have a worded description as a cause and effect relation and can be followed by an analytic formula of output-input connection. This systems operation results in the synthesis of several alternative physical principles of technical device operation in the form of circuits of serial conversions from input to output. But current difficulties in building mathematical models for description of synthesized variants of the physical principle of operation and evaluation of their performance characteristics do not allow quantitative comparison of these variants. Description of physical effects is not followed by a design study of technical realizations.
Conceptual design of sensing elements (sensors) for data measurement and control systems has some peculiar features. On the one hand it is possible to design fairly simple structural diagrams reflecting the principle of the sensor operation; on the other hand input of at least one new phenomenon to the knowledge base generates many new principles of sensor operation.

This paper discusses a conceptual model of knowledge classification based on energy-information models of circuits of different physical nature [5], [6]. The case of the model application for synthesis of multifunctioning sensors is described in [7].

2. Energy-Information Model of Circuits (EIMC)

Energy-information model of circuits (EIMC) enables switching to structural and formalized description of processes of sensor elements by using parametric structural schemes [5], [6]. The operation principle of any element of data measurement and control system is based on interaction of circuits of different physical nature, which is simulated in EIMC by the sequence of physical and technical effects. The EIMC uses the following notions:

- **Circuit** of a certain physical nature is an idealized material medium having defined geometrical dimensions and described in terms of physical constants inherent in phenomena of a given physical nature only.

- **Generalized circuit values** of the same physical nature are varying within wide limits and describe external action on the circuit of the given physical nature and the circuit’s response to this action. Main generalized values of EIMC: \( Q \) – charge, \( P \) – pulse, \( I \) – response, \( U \) – action.

- **Generalized circuit parameters** describe relative stability of a material medium in which physical process proceeds, these parameters are determined by geometrical dimensions, physical and chemical properties of the materials. Main generalized parameters of EIMC: \( R \) – resistivity, \( G = 1/R \) – conductivity, \( C \) – capability, \( W = 1/C \) – tension, \( L \) – inductivity, \( D = 1/L \) – deductivity (the value opposite to inductivity).

- **EIMC criteria** is a system of equations showing the relations between the generalized values and generalized parameters. The simplest set of parameters for systems with lumped parameters includes six equations [5].

The authors have discovered the systems of generalized-values and generalized-parameters to describe the processes in the circuits of different physical nature (mechanical, thermal, electromagnetic, hydraulic, optic, moisture transfer).

In addition to elementary links which reflect conversions inside the circuit corresponding to the EIMC criteria, links to physical and technical effects (PTE) to represent interaction of circuits of different physical nature with each other are introduced.

- **Physical and technical effect (PTE)** is a real cause and effect relationship, that reflects dependence between the input and output values of different physical nature through the conversion factor.

The whole variety of interactions between values and parameters can be represented in the form of a complex graph (figure 1) using energy-information models for description of circuits of different physical nature. The figure 1 shows the graph of physical and technical effects and in-circuit dependencies for n-circuits: mechanical, magnetic, electric and i-th physical nature circuit.

In the form of circuits of generalized values conversion based on EIMC, an expert describes existing physical phenomena and develops PTE passports [6] for a formal description of processes in technical devices.

Development of a PTE passport is a time-consuming process:
- it requires processing large amounts of information,
- it requires coordinated work of experts in different fields of knowledge,
- complex conversions of known physical equations to formulas containing EIMC values and physical constants,
- involves collection of expert evaluations of performance characteristics for multiple technical implementations of each PTE.

To solve this problem, we can use the ontological knowledge base of physical and technical effects.
3. Ontological Knowledge Base to Support Expert Analysis

Ontology is a system of fundamental concepts that provides the developer with an opportunity to model and represent a certain area of the world from the point of view of axiomatic definitions and taxonomic structures [8]. In the context of our task, it is the system of the above EIMC notions.

We suggest using the following types of ontologies to describe the energy-information model:

1. **EIMC model ontology** determines notions of this model (a circuit of a certain physical nature, values, parameters, inter-circuit physical effects, EIMC criteria). See figure 2.

2. **Physical effects ontology** describes classification of physical effects, represents correspondence between EIMC values and parameters and physical values and constants.

3.1. Example of Transformation of Physical Phenomena through EIMC

The task to make an energy-information model of PTE is rather time-consuming, since a proper combination of formulas in a broad list of the existing ones has to be found to bring the initial dependence of physical values to a well-defined form of interrelation of the EIMC analogue-values.

Let us look at the example of classification through the EIMC of a physical phenomena – the Hall effect (production of a voltage difference (the Hall voltage) as a result of a current flow curvature in metals in the magnetic field).

If a conducting plate (made of metal or semi-conductor) of thickness $d$ has a direct current $I_e$ passed in one direction, and magnetic field $B$ (induction density) applied in another direction, then voltage $U_e$ (the Hall voltage) can be measured in the third direction; this voltage is changing, as formula (1) shows, proportional to the magnetic force and current density:

$$ U_e = R_H \cdot d^{-1} \cdot B \cdot I_e , $$(1)

where $R_H$ is the Hall coefficient equal to the ratio of carrier mobility to the material specific conductivity.

To implement the energy-information model of this effect, formula (1) has to be converted so as to turn magnetic field $B$ into magnetic flux $Q_{mg}$, which is the EIMC value. To achieve this, equation (1) can be converted in the following ways:
\( U_e = R_H \cdot d^{-1} \cdot B \cdot I_e \cdot S \cdot S^{-1} = R_H \cdot (d \cdot S)^{-1} \cdot (B \cdot S) \cdot I_e = K_{Q_{mg}I_e} \cdot Q_{mg} \cdot I_e \), \hspace{1cm} (2)

where \( S \) is the sensing area of Hall effect sensor (1-50 mm\(^2\)).

\( Q_{mg} = B \cdot S \) - a magnetic flux perpendicular to the sensing area is a generalized EIMC value.

We obtained formula (3) of the conversion ratio for the energy-information model of the Hall effect. The effect model has two inputs – \( Q_{mg} \) and \( I_e \), and one output – \( U_e \).

\[
K_{Q_{mg}I_e}U_e = R_H \cdot (d \cdot S)^{-1},
\]

(3)

3.2. Ontology Knowledge Base and Software to Support the Expert Analysis

We have developed the knowledge and correspondence base of physical values and their EIMC equivalents to reduce expert labor input in classification of physical and technical effects. This knowledge base can be used to search for formulas which enable conversion of formulas known in physics into the EIMC adopted form.

We have proposed the following algorithm to solve this task. The user inputs the request in the form of values and constants that are used in the initial formula. For instance, for the reviewed Hall effect the request will be as follows:

\[
U_e, R_H, d, B, I_e,
\]

(4)

Then the request is processed by the system and then the result of its interpretation is displayed to the expert:

\[
U_e \quad "\text{voltage} // \text{physical value}" ,
R_H \quad "\text{Hall constant} // \text{constant value}" ,
\]
Each request component is interpreted as a physical value or a constant value. If unambiguous request interpretation is found impossible, the user will be offered the choice of options found in the data base, for instance: "speed // physical value" or "volume // physical value".

The task is to convert the initial list of physical values and constant values into the list containing EIMC analogue-values only and the values having constant values within the physical dependences considered. For the example in review we have:

\begin{align}
U_c & \quad \text{"EIMC analogue-value"}, \\
R_H & \quad \text{"constant value"}, \\
d & \quad \text{"constant value"}, \\
B & \quad \langle \text{conversion required} \rangle, \\
e & \quad \text{"EIMC analogue-value"}.
\end{align}

The system identifies values \((V_1, V_2, \ldots, V_n)\), that have to be converted and selects proper set of formulas \((F_1, F_2, \ldots, F_m)\) using the knowledge base of physical value dependencies and EIMC analogue-values. The conversion results in the set of EIMC analogue-values \(\langle E_1, E_2, \ldots, E_p \rangle\) and the set of constant values \(\langle C_1, C_2, \ldots, C_q \rangle\):

\[
(V_1, V_2, \ldots, V_n) \xrightarrow{F_1, F_2, \ldots, F_m} \langle E_1, E_2, \ldots, E_p \mid C_1, C_2, \ldots, C_q \rangle,
\]

In this case the task is to convert \(B\) magnetic field induction. The knowledge base has information of the following dependence \(Q_{mg} = B \cdot S\) (object F3). The reason to consider object F3 as a candidate formula to convert value \(B\) is that the knowledge base contains the fact “F3 uses B”. Results:

\begin{align}
F_3 & \quad \text{defines} \quad Q_{mg} \\
F_3 & \quad \text{uses} \quad S \\
Q_{mg} & \quad \text{is} \quad \text{EIMC value} \\
S & \quad \text{is} \quad \text{Constant value}
\end{align}

“EIMC value” and “Constant value” are the classes of the ontology knowledge base.

Thus, the result of using formula \(F_3\) contains EIMC analogue-values and constant values only. Hereon the search of formulas is completed.

\[
\langle U_c, R_H, d, B, I_e \rangle \xrightarrow{Q_{mg} = B \cdot S} \langle U_c, I_e, Q_{mg} \mid R_H, d, S \rangle,
\]

As seen from equation (6), the conversion factor of the resulting elementary unit of the parametrical structural scheme will contain the following constant values: \(\langle R_H, d, S \rangle\).

Figure. 3 shows the fragment of ontology class hierarchy.

Figure 3. Fragment of the PTE Ontology Knowledge Base.

A fragment of ontology filling with facts is presented in the form of a diagram below in figure 4.
Figure 4. Abstract from Ontology Filling.

Figure 4 shows the following facts (see table 1):

Table 1. The explanatory to figure 4.

| Fact | Description |
|------|-------------|
| F1.1 hasMember Rn | d is Constant |
| F1.1 hasConstant d | B is Value |
| F1.1 hasMember B | Ue is Value_EIMC |
| F1.1 is DefinitionOf Ue | Ie is Value_EIMC |
| F1.1 hasConstant Ie | |
| F1.1 is Formula | |

The knowledge about nesting object properties in the ontology enables, by the results of ontology classification (using inference engine), adding implicit properties, in this case implicit objects of hasMember property (d, Ue, Ie).

4. Conclusion

The proposed complex of information processing methods in the knowledge base by physical effect provides an opportunity to create unique reference systems and to reduce expert labor input in creation of passports of physical and technical effects and to optimize search for multiple evaluations of performance of technical implementations of these effects.

Ontology and subsystem architecture for ontology management developed by the authors facilitate information search for experts and performance evaluations to be included into each PTE passport. This enables quantitative assessment of each solution and selection of the best one using the complex structured criteria.

References

[1] Altshuller G (Altov H) 2008 And Suddenly the Inventor Appeared (Worcester, MA: Technical Innovation Center)
[2] Altshuller G 2000 The Innovation Algorithm (Worcester, MA: Technical Innovation Center)
[3] Pahl G, Beitz W 1995 Engineering Design (Berlin: Springer-Verlag)
[4] Koller R 1985 Konstruktionslehre für den Maschinenbau – Grundlagen des methodischen Konstruierens (Berlin: Springer)
[5] Zaripov M, Petrova I and Zaripova V 2002 Proc. Joint IMEKO TC-I & XXXIV MKM Conference Education in Measurements and Instrumentation - Challenges of New Technologies vol I (Wroclaw: Oficyna Widawnicza Politechniki Wroclawskie) pp 171-176.
[6] Petrova I, Zaripova V 2007 Int J Information Technologies and Knowledge 1 37-43.
[7] Petrova I, Shikulskaya O and Shikulskiy M 2014 Advanced Materials Research 875-877 pp. 951 - 956 doi: 10.4028/www.scientific.net/AMR.875-877.951
[8] Guarino N, Giaretta P 1995 Towards very large knowledge bases—knowledge building and knowledge sharing (Amsterdam: IOS Press) p 25–32