THE COOPERATIVE MULTI-SENSOR SYSTEM BASED ON BELIEF CONCEPT

Q. Liu, M. Hiraki and S. Ozono
Department of Precision Engineering, School of Engineering
The University of Tokyo, Hongo 7-3-1, Bunkyo-ku, Tokyo, Japan

Abstract: When constructing the sensing system using multi-sensor, two major tasks must be achieved: one is to build up the entire structure of the sensing system and the other is to show the algorithm for processing a huge amount of information obtained by the system. In this paper we propose the active multi-sensor system with knowledge-base and also the system based on belief concept closely related with knowledge-base, with making sensors cooperative.

Keywords: Cooperative sensor system, Active sensing, Belief, knowledge-base sensor system

1 SENSING SYSTEM WITH KNOWLEDGE-BASE

When we use sensors to get information about an object being concerned, we need to give prior to sensing some knowledge on the object to the sensing system. The knowledge is usually obtained through "recognition", which is the combination of "perceptual" (sensory, perception, representation) and "reasonal"(concept, judgement, reasoning), by extracting common attributes of the objects to be sensed[1)].

Generally individual objects, which consist of certain extension of concept, are distinguished by accidental attributes of the objects[1)]. X_j $(j=1,\cdots,J)$ is the j th individual object belonging to the extension of concept X, and x_i $(i=1,\cdots,I)$ is the i th accidental attribute of concept X. The individuality of J individual objects can be expressed by the actual expression of I accidental attributes x_i $(i=1,\cdots,I)$. In order to utilize accidental attributes, accidental attribute vector $\vec{X}_j=(x_1,\cdots,x_i,\cdots,x_I)$ is introduced, and individuality of an individual object can be expressed by the accidental attribute as follows:

$$X_j = F(\vec{X}_j) \quad (j=1,\cdots,J) \tag{1}$$

where, F is 1:1 correspondent function.

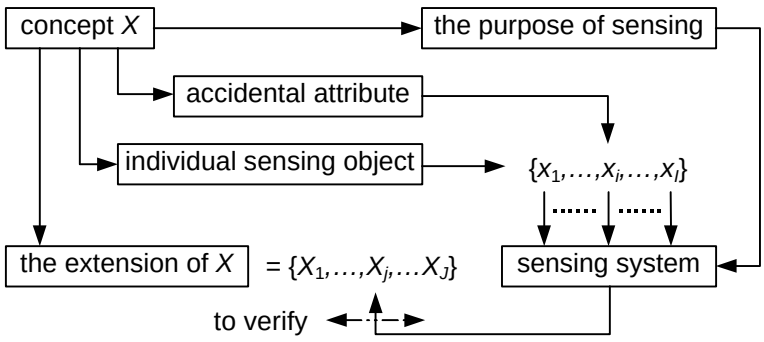

Figure 1. Concept of sensing operation based on the knowledge-base of the individual sensing object

If sensors can detect actual values of accidental attributes of the individual object, which belongs to certain concept, the individual object itself can be expressed by the sensing system. In such case an individual object is called individual sensing object. The purpose of sensing operation is "to make clear

whether the individual sensing object is a special individual object of the given concept or not". Sensing operation is "the operation to obtain the information about the actual expression of the accidental attributes on the individual sensing object by the help of sensors". In order to realize the purpose of sensing operation, the information obtained by sensors is processed by making the best use of the given concept and knowledge, and the individuality of the individual sensing object is verified on the extension of the given concept. Diagram of the sensing operation is shown in figure 1.

2 SENSING OPERATION BY THE MULTI-SENSOR SYSTEM AND ITS TYPES

In order to measure the individuality of certain individual sensing object it is necessary to sense the actual expression of the plural accidental attributes by multi-sensor system. On the contrary, in order to ensure the accuracy of the obtained information from the plural sensors and the sensing behavior, it is necessary to use multi-sensor system for the sensing of the same accidental attribute of individual sensing object. For these two necessities multi-sensor system is essential in the sensing system. There are two types of multi-sensor utilization, as shown in figure 2, i.e., the plural sensors toward the plural attributes, and the plural sensors toward the single attribute.

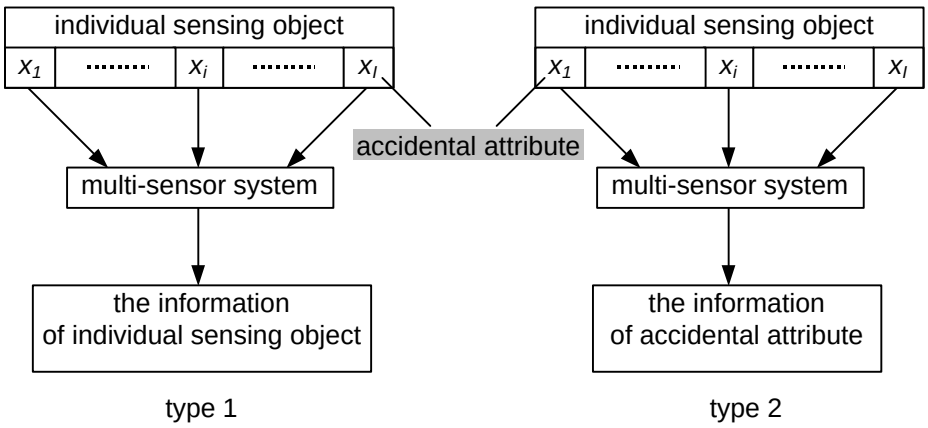

Figure 2. Two types of the multi-sensor system utilization

3 STRUCTURE OF THE COOPERATIVE MULTI-SENSOR SYSTEM

3.1 The relationship between cooperation and knowledge

In the multi-sensor system, the cooperation of the sensors means the harmonization of effectively unifying the information obtained from each sensor and is essential. The sensor cooperation is divided into four types, multi-sensor, integration, fusion and association [2)]. On the analogy of research on human recognition activity, it can be said that associated knowledge about an individual sensing object is the most important to realize the cooperation of sensors for a multi-sensor system.

3.2 Structure of the cooperative multi-sensor system

Figure 3 shows the structure of the cooperative multi-sensor system. Main-system is constituted of a sensing system and an actuator system to control the location of the sensing system. The sensing system is made up of sensor system using multi-sensor, sensor-information choosing system, actuator system for the sensor, and operation-method-choosing system and knowledge database. The knowledge database is used for explaining the sensor information and controlling each system.

The configuration of the sensor in the sensing system is designed so as to fit the accidental attribute of the individual sensing object. Suppose that a multi-sensor is used in the sensing system for the same accidental attribute, and the multi-sensor constitutes the sensor group. The sensing system works with the sensor groups when the individuality of the individual sensing object is sensed; and works with the sensors in each sensor group when the accidental attribute is sensed. Therefore there are two kinds of cooperation in the sensing system: one is the cooperation of the sensor groups; the other is that of the sensors in a sensor group.

In the sensing system, the three sub-systems, i.e., actuator system for sensor, operation-method-choosing system and sensor-information choosing system, as shown in the figure 3, are pre-operated before doing the active sensing. The cooperation of sensors or of sensor groups in the sensing system can be realized with the three sub-systems by the help of knowledge database.

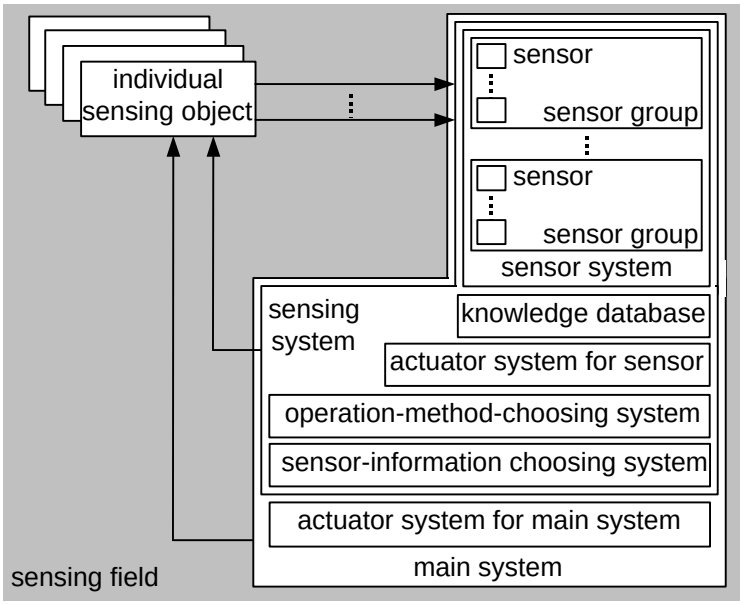

Figure 3. Structure of cooperative multi-sensor system

4 BELIEF AND THE SENSING BASED ON BELIEF

Belief, B, is a judgment, that expresses an object or the relationship of certain objects by probability, based on the knowledge and the unreliability on the object[3]. From the belief concept of view, sensing can be regarded as verifying the individual sensing object to extension of the known concept by certain belief based on the known concept and knowledge. This verification is given by processing the information on the actual expression of the accidental attributes of the individual sensing object, which has unreliability caused by sensor-sensing behavior. As the sensing process proceeds, the value of belief on the individuality or the accidental attributes of individual sensing object changes.

5 THE STRUCTURE OF SENSING MODEL BY UTILIZING BELIEF CONCEPT

The sensing model is shown in figure 4, where C is the sensing behavior for information acquisition by a sensor in the sensing system and A is the moving behavior from one individual sensing object to another for the sensing system (see figure 3). Sensing is realized in the field where sensing is carried out, consisting of main system and the individual sensing object(s) of which concept is X, as shown in figure 3.

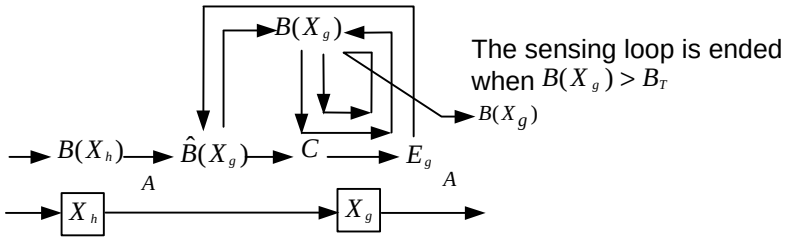

Figure 4. Sensing model based on belief

$X_h, X_g (h, g = 1, \cdots, H, h \neq g)$ are any two of H individual sensing objects in a sensing field and belong to the concept $\underline{X}$. Let $P(X_h)$ be the probability as X_h becomes the individual sensing object for the sensing system, and $P(X_g \mid X_h, A)$ be the probability as X_g becomes the individual sensing object for the sensing system by the moving behavior A from X_h to X_g at certain time, and we assume that both $P(X_h)$ and $P(X_g \mid X_h, A)$ are determinable.

When the sensing operation on X_h is found completed by monitoring the value of the belief on X_h, the sensing system switches to the sensing on X_g. The belief $B(X_h)$ that X_h is the individual sensing object of the sensing system at the initial stage of the sensing can be expressed by the equation (2).

$$B(X_h) = P(X_h) \tag{2}$$

If the value of belief $B(X_h)$ is below the given threshold value B_T, it is necessary to increase the belief value of the object X_h by further sensing on each accidental attribute of the individual sensing object; while if it is beyond the given threshold value B_T, the sensing system will give the estimated belief of the individual sensing object X_g by equation (3), and will transfer the belief of the individual sensing object X_g by equation (4).

$$\hat{B}(X_g) = \sum_{X_h} P(X_g \mid X_h, A) B(X_h) \tag{3}$$

$$B(X_g) = aP(E_g \mid X_g, C)\hat{B}(X_g) \tag{4}$$

where, $\hat{B}(X_g)$ is the estimated belief, $B(X_g)$ is the belief when X_g is the individual sensing object, E_g is the information on X_g obtained by the sensing behavior C, and a is the normalization constant.

As $P(E_g \mid X_g)$ is called "sensor model"[3], $P(E_g \mid X_g, C)$ in the equation (4) may be called "sensing model". The activity of the sensing model is not shown by giving the sensing behavior C blindly, but by instructing the sensing behavior C in the belief based on knowledge database. Through this instructed sensing behavior, i.e., $P(E_g \mid X_g, C)$, controlled by belief, sensor-cooperation can be realized. Figure 5 shows the cooperation of the sensor groups and the sensors realized using sensing behavior C by the help of belief. The shaded rectangles show the sensor in each sensor group; $S_i (i = 1, \cdots, I)$ is the sensor group; $B_i (i = 1, \cdots, I)$ is the local belief from S_i; B is the whole belief. And $C_i (i = 1, \cdots, I)$ is used upon the cooperation of the sensors in a same sensor group; while C_g is used upon that of the sensor groups.

By using this active sensing model, it can therefore be expected to reduce the sensing time and to simplify the information-processing, and as a result the sensing cost can be reduced.

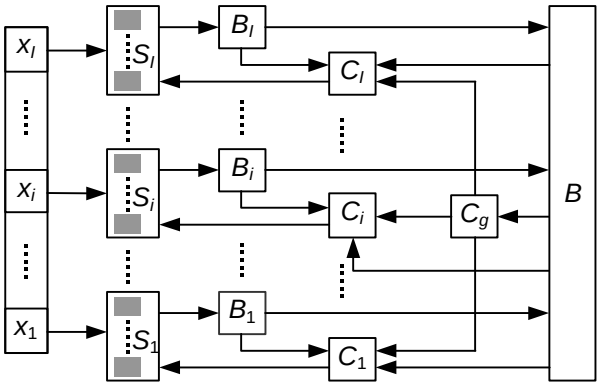

Figure 5. The cooperation realized using sensing behavior C by the help of the belief

6 SUMMARY

In this paper, by investigating the relationship between the sensing operation and the knowledge database, we defined the sensing operation, emphasized the necessity of applying the multi-sensor to a sensing system and proposed the cooperative multi-sensor system based on the knowledge database. Then by developing the discussion on the sensing system structure, we proposed the active

sensing model utilizing the concept of belief that is closely related with the knowledge database.

In our future research work, we will set up the experimental model and prove the usefulness of the active sensing model.

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AUTHORS: Ph.D Candidate Qing LIU, Research Associate Dr. Masahiko HIRAKI and Prof. Shigeo OZONO, Department of Precision Engineering, The University of Tokyo, Hongo 7-3-1, Bunkyo-ku, Tokyo 113-8656, JAPAN, Phone int. +81-3-5841-6472, Fax int. +81-3-5841-8556
E-mail: lq@ozono.pe.u-tokyo.ac.jp