Temporal Information Modelling in the Context of Intelligent Instruments

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Abstract: This paper presents the information modelling process in the context of intelligent instruments. The goal is to make the manipulation of measurement information possible with time response considerations. The presented approach focuses on the modelling of information entities and information dating. First, the context of the intelligent instruments is described. Then, information entity modelling is presented. Finally, interests and perspectives are presented in the context of intelligent instrument networking.

Keywords: Information, Modelling, Intelligent Instrumentation, Realtime.

1. INTRODUCTION

Intelligent instruments, i.e. intelligent sensors and actuators, are now commonly used in industry and home automation (Bloch *et al*., 1993; Spoelder *et al*., 1997). Recent studies (Benoit *et al*., 2000a; Riviere *et al*., 1996); Rumbaugh *et al*., 1991) discuss their design. Solutions that cut the design process into two pieces, based on the same instrument modelling, have been proposed to simplify the work of the software engineer and the physicist (Benoit *et al*., 2000a, b). In this kind of approach, supervisor information and automatic code generation can be obtained (Wollschlaeger *et al*., 2001; Perrin *et al*., 2002).

In order to facilitate interoperable functionality manipulations, intelligent instrument modelling can be based on external representation. Staroswiecki proposes to model a sensor by a set of services (Staroswiecki and Bayart, 1996). These services are organized into subsets called "USer Operating Modes" (USOM). In this model, a sensor service can be requested, and therefore serviced, only if the current active USOM includes this service. This makes it possible to use the services only when they are available.

The approach, discussed in (Bouras and Staroswiecki, 1997), proposes to model existing instruments from the external point of view. In particular, the external model of instruments can be used to build a global model for applications involving several instruments. This type of approach can also be used to define the internal functional model (Benoit *et al*., 2001) in order to simplify intelligent instrument development.

Information associated with the external point of view of intelligent instruments is often modelled by events. They are generally supposed to be immediately propagated onto the network. Currently, the delay of propagation of an event depends on:
- the type of network (TCP-IP protocol or fieldbus constraint with priority data level),
- the priority level especially when using fieldbus,
- the traffic on the bus.

At the network supervisor level, a node can be considered as a service provider. A general approach consists in considering services, independently of nodes. Then, the credibility of information, which is transmitted over the intelligent instrument network, depends on the time-response system and instruments effectively used.

In this paper, we investigate possible models to deal with functionalities expressed, at the application level, in terms of maximum accepted inaccuracies. Let us note that at the network level, information inaccuracies are due to network configuration. Therefore, it is difficult to integrate new needs for applications without calling into question the configuration of the network. The proposed models take into consideration time variation of data accuracy and refreshment operation consequences.

In section 2, several possible models dealing with uncertainty for information entities are introduced.

Section 3 focuses on refreshment modelling, including the case when events are not precisely known. Finally, a general model is proposed.

2. INFORMATION MODELLING FOR INTELLIGENT INSTRUMENT NETWORKING

2.1. Introduction

Introducing uncertainty at the application level leads to interesting problems in terms of decision. Let us illustrate one of them. At t_d time, a decision is required. At the application level, two possibilities are offered:

- the system may immediately take the available information from the network but with its uncertainty at that time (t_d),
- the system may decide to wait for the next refreshment operation to have more accurate information available at t_r. Let us note that, in the general case, information will be available on the network after a delay that depends on time computing and bus traffic. In the next sections, we will consider that the difference between t_d and t_r is negligible.

When uncertainty is not taken into consideration, the first strategy is the usual one. But, because uncertainty increases with time, it may lead to a poor decision because of the information quality. The second strategy is more complex but provides an interesting alternative. It requires a model for representing information entities with their uncertainty and a model associated with the refreshment process. This problem is illustrated in figure 1 where uncertainty is represented by a confidence interval.

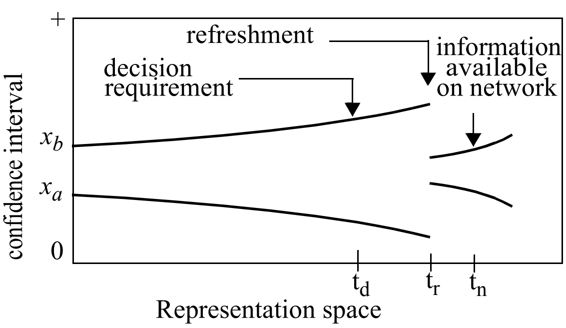

Fig. 1. Decision problem.

Another interesting feature, that comes from the explicit representation of uncertainty, is to define, at the application level, a threshold corresponding to the maximum acceptable inaccuracy as shown in figure 2.

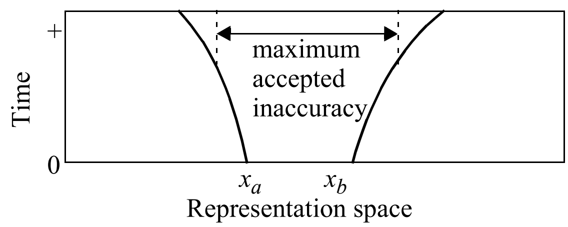

Fig. 2. Using an accuracy threshold.

This kind of consideration makes it possible to design intelligent instrument networking by including losses of variable accuracy. Thus, the accuracy desired on the application level is distinguished from the inaccuracies due to the technical choices. These can be propagated to the decision-making unit that can react being aware of, on the one hand inaccuracies of entrance information and, on the other hand, the desired accuracy resulting from the application level.

2.2. Representing uncertainty

The original role of instruments or nodes in an intelligent instrument network consists in linking a physical state with an information entity (Mari, 2001). The nature of this information entity depends on the chosen modelling. In a simple model, the information entity is a numerical value *x* on a representation space *X* as shown in figure 3. This figure shows the possibility distribution of the information entity. The degree of possibility for a value indicates the possibility that this value can represent the physical state.

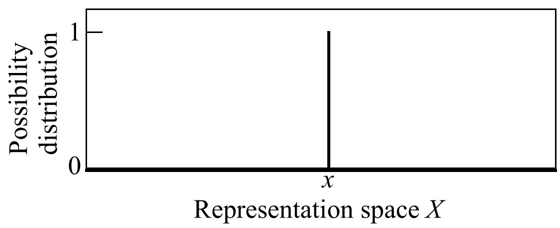

Fig. 3. Information entity as single value

Uncertainty can be added on measurement by means of a confidence interval as shown in figure 4. It is then represented by a couple (x_a, x_b).

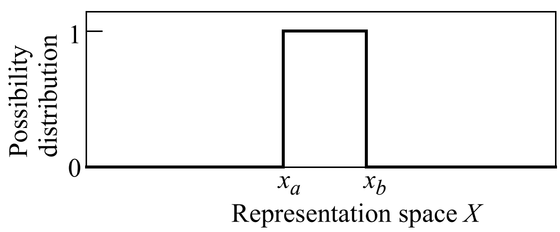

Fig. 4. Information entity as a confidence interval.

This modelling can be extended to a more complete one based on the possibility theory. Studies on use of the possibility theory for measurement and data fusion consist in retaining the model representation that is the most representative of experimentation results and which can be easily manipulated to facilitate mathematical operations and propagations from information. In (Mauris *et al.*, 2001), pseudo-triangular possibility distribution is presented to model uncertainty in measurement. The links between probability distributions and pseudo-triangular distribution are also described. In this paper, it is assumed that the reader is familiar with possibility distribution. Therefore, the related mathematical models will not be reintroduced.

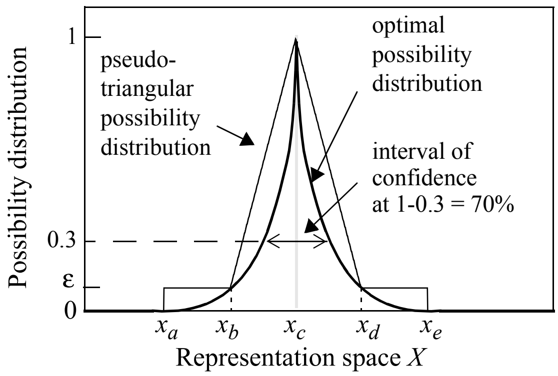

Fig. 5. Information entity as a triangular possibility distribution (Mauris *et al.*, 2001).

2.3. Time variation consideration.

The simplest model is obtained when considering that time does not influence information entities, as represented in figure 6, that is information entities are static.

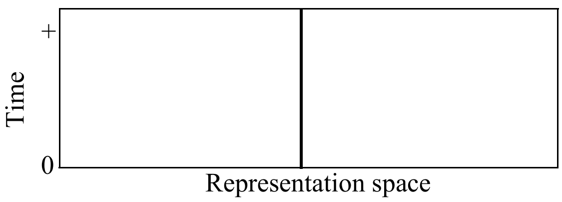

Fig. 6. Static information entity.

An information entity can also be considered as constant in time during a known period t_p and unknown after this period. This model, shown in figure 7 and based on information entity lifetime, is implemented into fieldbus like WorldFIP.

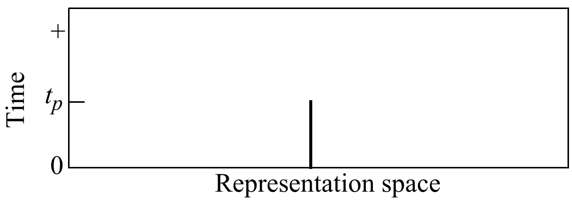

Fig. 7. Limited lifetime information entity.

The time variation of information entities, that are dynamic information entities, can also be taken into account as shown in figure 8.

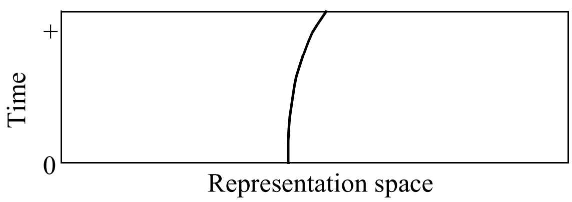

Fig. 8. Dynamic model of an information entity.

Now, the previous model can be augmented to deal with uncertainty associated with information entities. We will assume that information entity inaccuracy increases with time. Figure 9 shows the time evolution of a static information entity that is precisely known at time $t = 0$. As time increases, the uncertainty associated with the entity also increases. Figures 10 and 11 represent respectively static and dynamic information entities that are defined by an interval at $t = 0$ as described in figure 4. In a similar representation, figures 12 and 13 correspond to the case where uncertainty is represented by means of a pseudo-triangular possibility distribution as shown in figure 5.

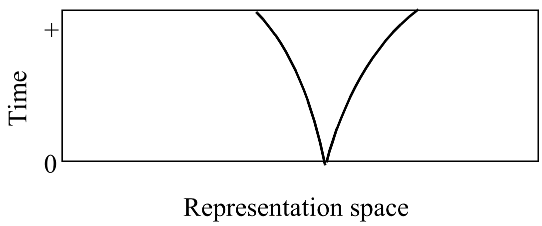

Fig. 9. Precise static information entity with an interval based uncertainty.

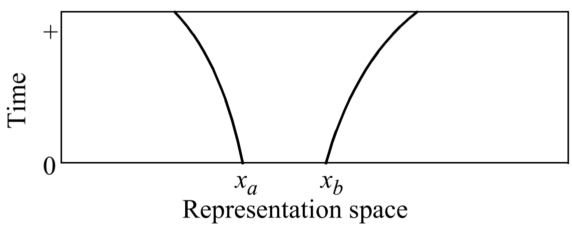

Fig. 10. Static information entity with interval based uncertainty.

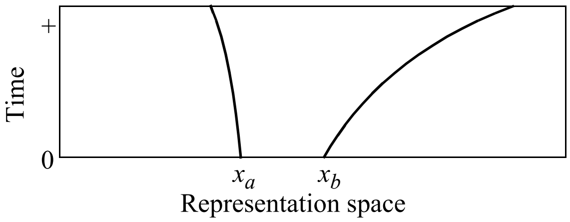

Fig. 11. Dynamic information entity with interval based uncertainty.

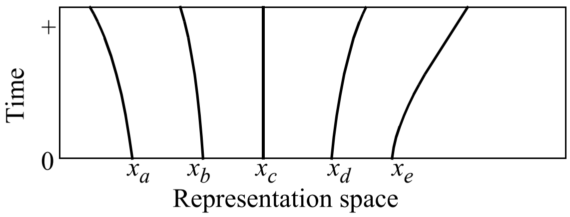

Fig. 12. Static information entity associated with triangular possibility distribution.

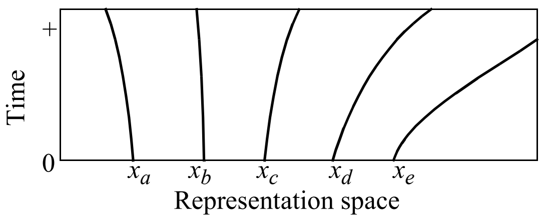

Fig. 13. Dynamic information entity associated with triangular possibility distribution.

3. REFRESHMENT MODEL

3.1. Refreshment operation

Another possible extension of this approach consists in taking into consideration the time refreshment period or an assumed date of refreshment. The refreshment process will update the information entity with the measurement value which will be acquired at the refreshment date.

The refreshment principle is illustrated in figure 14 in the case of a static information entity.

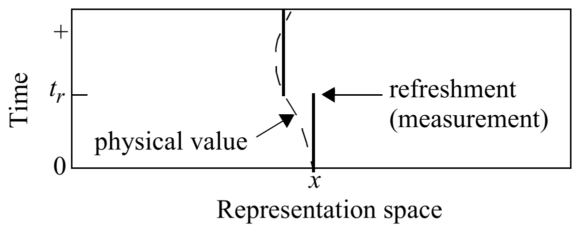

Fig. 14. Static information entity during refreshment.

In order to prevent too large differences between the physical value and its representation by an information entity, a lifetime may be defined. In that case, if the information entity lifetime is smaller than the refreshment period, then the model given in figure 7 can be used which leads to the behaviour represented in figure 15.

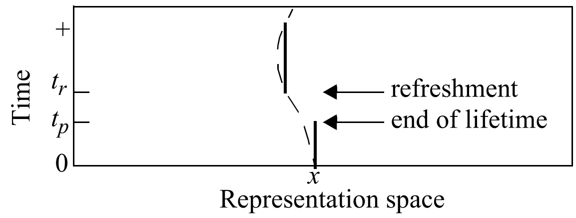

Fig. 15. Information entity with lifetime

A better solution, if available, to reduce the difference between the physical value and its representation is to use a dynamical model that is periodically refreshed as shown in figure 16.

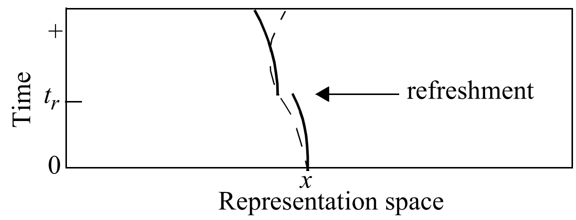

Fig. 16. Dynamic modelling with refreshment operation

This refreshment principle can also be applied when coping with uncertainties. If not refreshed, the confidence intervals (or the alpha-cuts of the possibility distribution) increase with time. It leads to large intervals which do not provide any more pertinent information. The refreshment process will re-synchronize the uncertainty based model with the physical value which will be acquired at the refreshment time as shown in figures 16 and 18.

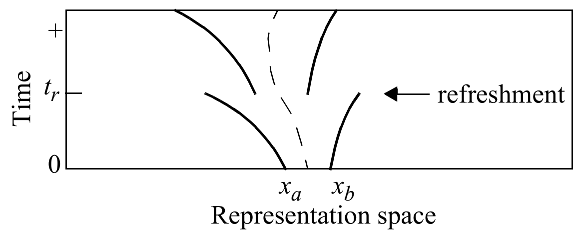

Fig. 17. Refreshment process with a dynamic model including interval based uncertainty.

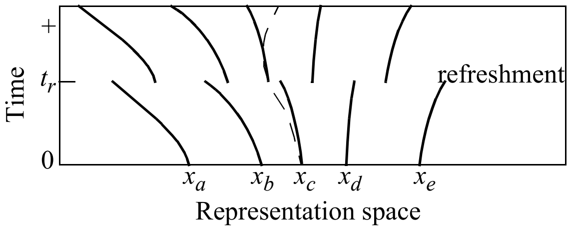

Fig. 18. Refreshment process with a dynamic model including possibilistic representation of uncertainty.

3.2. Refreshment modelling

An interesting concept is to consider that refreshment dates can not in themselves be precisely known. For example, this may occur in the case of periodical refreshment due to network traffic. Therefore, instead of modelling the refreshment by a single event, time confidence interval can be introduced.

As shown in figure 19, there is now a family of possible trajectory for the information entity depending on when the refreshment effectively occurs in the time window.

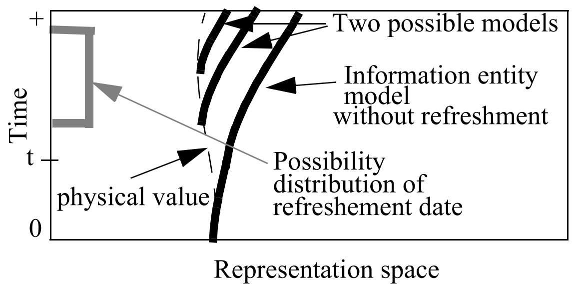

Fig. 19. Illustration of refreshment modelling based on a time confidence interval.

Dealing with time confidence interval generates a more complex decision problem. Figure 20 illustrates this complexity with the problem that was presented in figure 1. A decision has to be taken at time t_d whether to pick up the available information or to wait for more, knowing that the refreshment will occur in the time interval $[t_{r\,min}, t_{r\,max}]$.

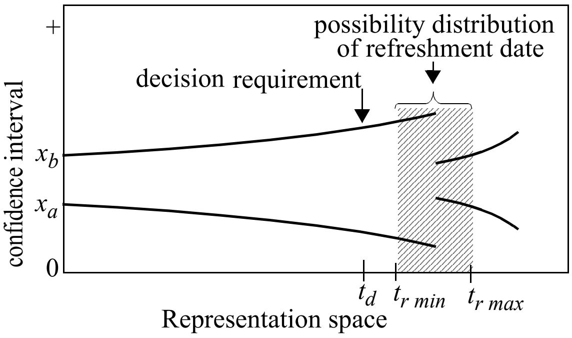

Fig. 20. Decision problem with time confidence interval.

3.3. Final model

All previous concepts can be used to define a general information entity model by considering:

- a function *v*, possibly constant, representing time variation of the information entity,

- a distribution shape *s* for the uncertainty representation. This distribution is characterized by a set of coefficients x_{si} depending on *s*.

- a function *p*, possibly constant, representing time variation of the coefficients x_{si}.

- a distribution shape *r* for the uncertainty of refreshment dating. This distribution is characterized by a set of coefficients x_{ri} depending on *r*,

- the date of creation (or last refreshment).

Therefore, the information entity model is formally defined as follows:

$$\text{IE} : \langle v, s, p, r, date \rangle \quad (1)$$

This model can now be implemented to be sent over the network as shown in the next section. When received by a node, it can compute the uncertainty associated with the information entity at any time.

The next section presents an example.

3.4. Example

In this section, we propose to illustrate information entity in the context of a network of intelligent instruments. We suppose that nodes are equipped with synchronous clocks to be able to process data. Indeed, the date of creation is included in the information entity as shown in the preceding section.

To be transmitted over the network, information entities are first coded as frames. According to the previous section, frames have five fields, each one being associated with one piece of the information entity. As represented in figure 21, a field identifier, followed by parameters, is used to characterize the nature of the first four fields.

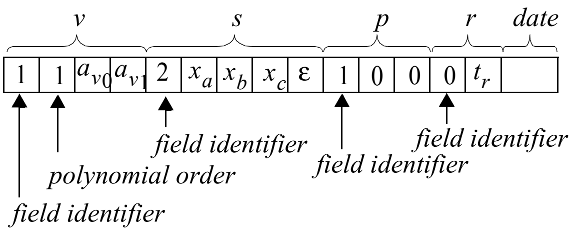

Fig. 21. Example of a frame.

The frame example provided in figure 21 is related to the following model:

- The time variation of the information entity, that is the function v, is described by a polynomial of order 1. The field identifier is 1 for polynomial, followed by the order of the polynomial and its coefficients. Thus, the function v is affine in time, that is:

$$v = a_{v1} \cdot t + a_{v0} \tag{2}$$

- The uncertainty is represented by means of a symmetrical pseudo-triangular possibility distribution (see figure 5). The associated field identifier is 2 followed by the 4 parameters x_a, x_b, x_c and ε characterizing the distribution shape s.

- Coefficients of the distribution shape are assumed to be constant. It is coded as a 0-order polynomial.

- The refreshment delay, taken from the creation date, is assumed to be precisely known. Therefore, the associated distribution shape is a singleton possibility distribution as shown in figure 3. The field identifier is 0 for singleton shape, followed by the delay value. Here, we have:

$$r = t_r \tag{3}$$

Once received, this frame can be used by any intelligent component connected to the network to compute, at any time, the uncertainty associated with the transmitted information. Let us illustrate the principle.

Assume that a sensor has performed a measurement and sent the result over the network. Assume also that another component is willing to use the transmitted information and needs to compute its uncertainty at absolute time t. First, the relative time, with respect to the birth date of the transmitted information, is computed, that is:

$$t' = t - date\,. \tag{4}$$

Then, each field are processed according to its identifier in order to provide the time expression of the coefficients associated with the uncertainty distribution shape.

In the chosen example, four coefficients of the pseudo-triangular possibility distribution are directly obtained from the second field of the frame, that is x_a, x_b, x_c, and ε, the two others, x_d and x_e, are obtained by symmetry. Thus, the uncertainty is characterized by the following set of equations:

$$x_a(t) = x_a + a_{v_1} \cdot t' + a_{v_0} \tag{5}$$

$$x_b(t) = x_b + a_{v_1} \cdot t' + a_{v_0} \tag{6}$$

$$x_c(t) = x_c + a_{v_1} \cdot t' + a_{v_0} \tag{7}$$

$$x_d(t) = 2 \cdot x_c(t) - x_b(t) \tag{8}$$

$$x_e(t) = 2 \cdot x_c(t) - x_a(t) \tag{9}$$

$$\varepsilon(t) = \varepsilon \tag{10}$$

Figure 22 illustrates, using the same graphical representation as in the previous sections, the link between the frame received by the component and the reconstructed uncertainty.

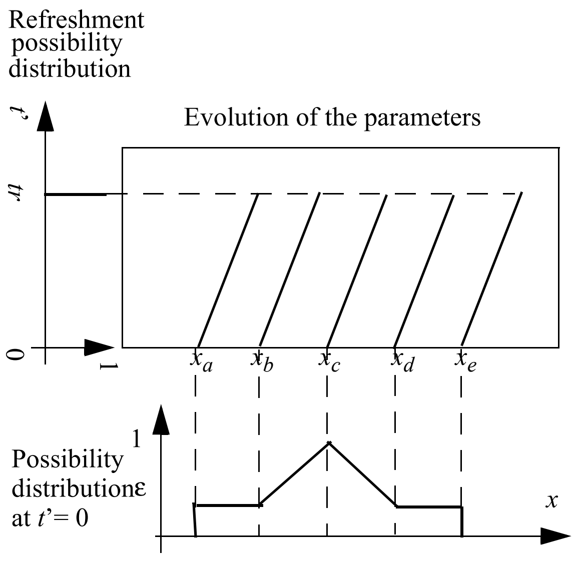

Fig. 22. Uncertainty computed by the intelligent component from the received information entity.

4. CONCLUSION

Measuring accuracies are currently the subject of much research. In this paper, a general model has been presented that makes it possible to compute the uncertainty associated with each information entity at any time. It makes possible to distinguish accuracy loss due to configuration design from imposed accuracy requested at the application level. In addition, taking into account refreshment in the model is an interesting track to improve the quality of the decision in many problems. By doing so, real time problems associated with instrument functionalities are brought back to the application level.

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