Toward a methodology for designing Intelligent Manufacturing Systems :

A set of Meta-rules and their application to a greenhouse.

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ABSTRACT.

Usually, manufacturing systems automation has been developed using data from products. This is well suited to manufacturing industries where transformational processes implement actuators. This is not so obviously apparent in agriculture or agrofood industries where the product is a living product : the product acts by itself in the transformational process.

We show in this paper how to analyse such a system taking into account the living product as a participant of its own transformation. This functional analysis is built with a classical and well-known method in automation : IDEF-O. This method is easy to use, easy to understand and allows an efficient dialogue between specialists and non-specialists. Unfortunately, the method is syntaxically driven.

Our approach intends to add to this method a set of meta rules that we will describe and explain. These meta-rules will provide the method with a semantics. IDEF-O will permit to identify flows and operators of the systems. The semantics will enable us to generate skeletons for informational and behavioural modelling of the system.

These concepts have been applied to the functional analysis of a greenhouse. In this example, the greenhouse is seen as an Intelligent Manufacturing System restricted to Control Maintenance and Technical Management. The results of the functional modelling step have been used to generate the skeleton of a technical management data base.

The technical management data base had been implemented under the ACCESS software. This informational system is the kernel of the Intelligent Manufacturing System, providing :

- Intelligent control as regards different strategies : to minimize energy consumption, to optimize the growth of plants...
- Predictive maintenance as regards actuators, product behavioural modelling and climate simulation.

1. Introduction

1.1. From CMMS (Control, Maintenance and technical Management System) concept ...

Current applications of automation and computer systems in the manufacturing industry have been considered as separate islands of automation: the "Control island", the "Maintenance island" and the "technical Management island". The main goal of a manufacture plant manager is to make a subsequent profit by an optimization of costs. To achieve this goal it is necessary to link the three previous automation islands :

- to proceed safely through the "Control island" by distributing intelligence upon actuators and sensors (Figure 1.);
- to increase the plant availability through the "Maintenance island" to replace curative or scheduled maintenance by predictive just in time maintenance;
- to optimize production and maintenance costs, the "Management island" is integrated with the two previous activities.

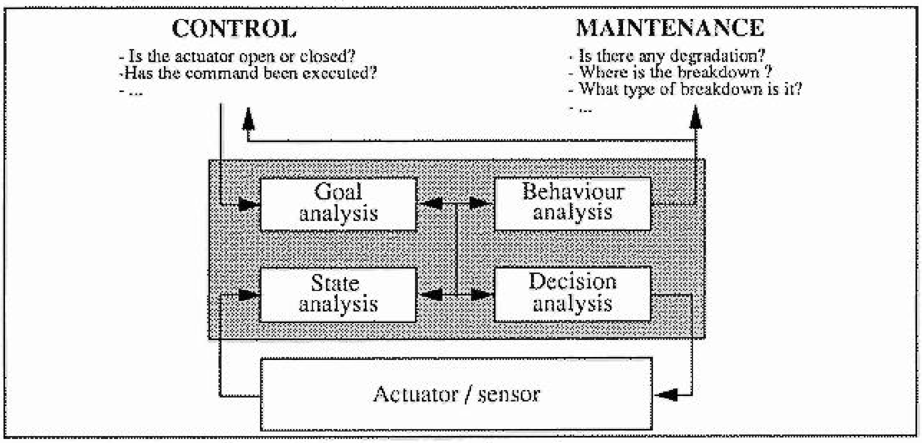

Figure 1. *intelligent actuation and measurement*

The CMMS concept had been developed in the framework of the the DIAS project : CIME ESPRIT II 2172, *Distributed Intelligent Actuators and Sensors* (DIAS). Today, DIAS is going on through the PRIAM project : CIME ESPRIT II 6188 *Prenormative Requirements for Intelligent Actuation and Measurement* (PRIAM). From a Computer Integrated Manufacturing (CIM) point of view, automatisms are tools which must be closely linked with others - for example : control, maintenance, quality and technical management - to achieve a good result :

- to increase the added value (by reducing cost and delay for example),
- to increase the quality of products.

According to these targets, our aim is to prototype a Control, Maintenance and Technical Management System for greenhouses. According to this aim, this paper introduces a methodology that we did follow to analyse and design the prototype. Especially this paper focuses on the technical management function. Consequently, this paper presents :

- the functional analysis of the whole system,
- the information system analysis and design,
- the links between functional and informational modelling steps.

Our work is inspired by research results carried out in the manufacturing field [LHO85], and more precisely :

- the concept of the intelligent actuator [IUN92],
- the distribution of intelligence down to the level of actuators and sensors that requires a new automation engineering approach [MOR94].

1.2. ... toward its application in a greenhouse

A greenhouse is a complex system. The main components of this system are energy transfers and biological processes. A microclimate is created in the greenhouse in order to ensure the best growth of plants. Plants which are grown inside, need a nutritive solution. The organic composition of this nutritive solution is chosen in order to ensure the best growth of plants.

Up to now, both microclimate and nutrition have been automated.

Temperature, hygrometry and light are supervised and regulated according to orders and set points which are given by the greenhouse keeper.

Quantities of water and fertilizers are regulated according to the volume and the acidity of the nutritive solution. The organic composition of the nutritive solution is defined by the greenhouse keeper.

Classical manufacturing operations are transformation, transportation and storage. In these operations are acting technological components so called actuators. Manufacturing of food products is also requiring actuators. But the main difference lies in transformational operations where are acting biotechnological components. We have already introduced the concept of bio-actuator [GER93]. In the present greenhouse framework we consider plants as bio-actuators. That is to say that plants are not only products to be manufactured but they are components of the manufacturing system.

2. Methodological approach

The methodological approach followed (Figure 2.) is made up of three steps:

- functional analysis of the manufacturing system,
- behavioural modelling of basic activities,
- information system analysis and design.

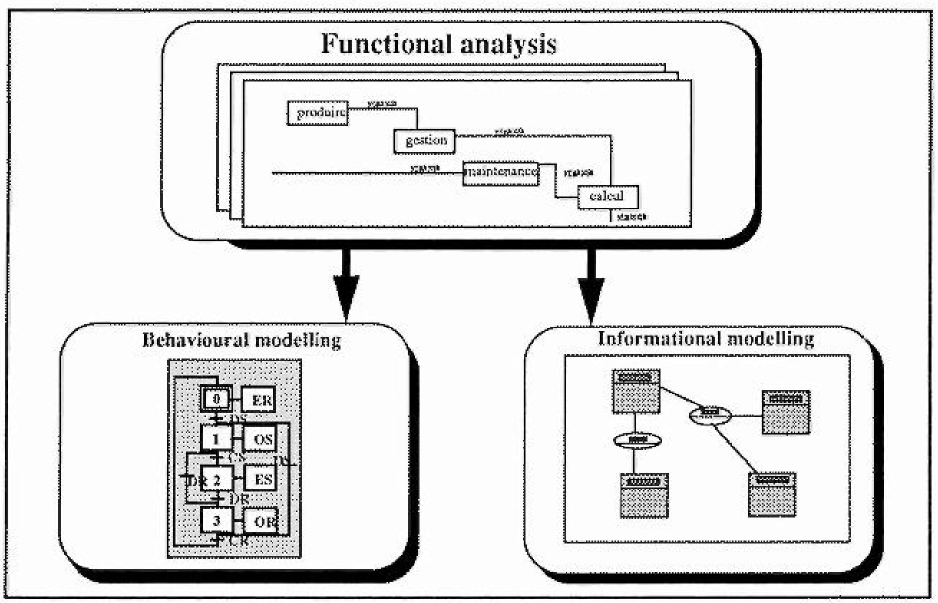

Figure 2. Methodological approach

The functional analysis step uses the IDEF-0 syntax and a semantic describe by a set of meta-rules. This semantic driven approach will enable us to establish semantic links between functional analysis step and the two following steps : behavioural and informational modelling.

The behavioural modelling step and its link with the functional analysis step have been already introduced and validated :

- behavioural modelling of control functions, actuators and bio-actuators with sequential flow charts or synchronous language [GER93];
- link with the functional analysis throuh the grid mecanism [LHO85].

The targeted implementations of this step are control and maintenance functions.

The informational modelling step uses the entity-relationship formalism as describe in [AFN92]. The target implementations of this step are the technical management function and its links with control and maintenance functions.

2.1. Functional analysis

2.1.1. IDEF-0

IDEF-0 [IGL89] is a structured and hierarchical system analysis method. This method is well suitable to carry out the functional analysis of manufacturing systems because the syntax is very easy to understand(Figure 3.).IDEF-0 allows an efficient dialogue between all partners involved, for example, in an automation project.

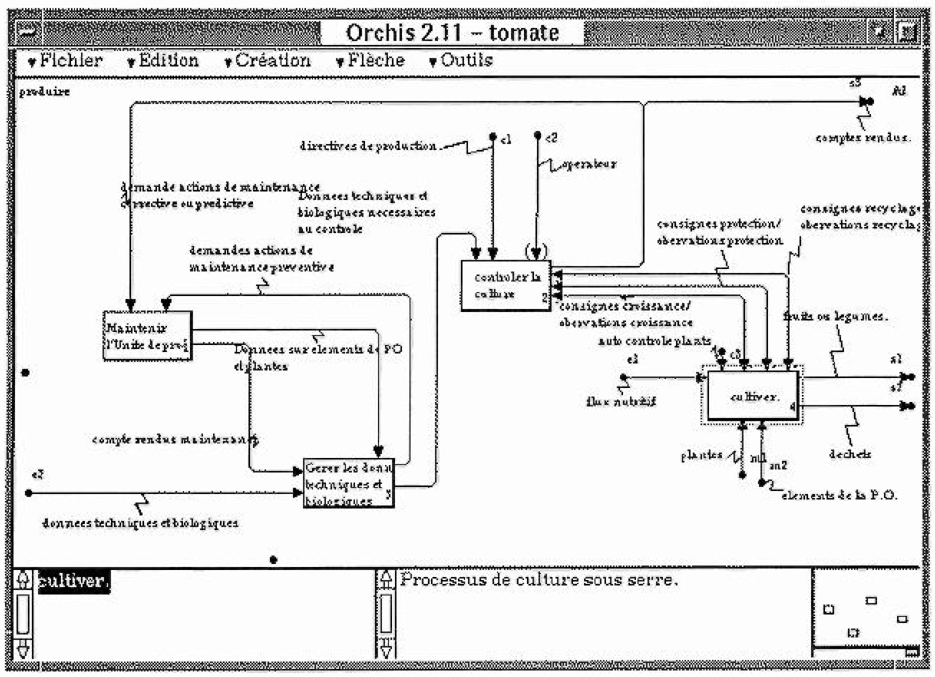

***Figure 3.** Functional analysis of greenhouse, introducing CMMS functions*

The snag is that the practice of IDEF-0 can be incompatible with re-usability because on the one hand IDEF-0 leaves all functional and structural choices to the automation engineer since the semantic is poor.

On the other hand the system is not identified, it is only described. The classic IDEF-0 approach leads us to answer the following question: «What is the system made of ?» which is a typical cartesian question. IDEF-0 helps us to answer this question applying a typical cartesian decomposition. Decomposition rules are especially syntaxically driven. Once more, this fact is incompatible with re-usability. Any changes in the definition of the manufacturing system will require the expansion of a new model.

2.1.2. Operators and flows

Nevertheless, IDEF-0 allows us to point out the basic components of the manufacturing system. They are also called basic system operators. [LEM90] suggests the following classification of operators:

- ***Time operators*** are modifying time location of materials;
- ***Space operators*** are modifying space location of materials;
- ***Shape operators*** are modifying shape of materials.

Storage, transportation and transformation functions implement, respectively, time,space and shape operators.

This set of operators is completed with the ***Nature operator*** which represents a transmutation [LEG92]. That is to say : « a change in the nature of flows, and not only a shape or structure modification». Interface functions between «control/command» functions and «manufacturing» functions implement nature operators.

Every IDEF-0 functional box is characterised by relations with its environment. These relations refer to four typical kinds of flows:

1. ***«To do» flows*** are operands or achieved goals of the system;
2. ***«Can do» flows*** are the means which are required by the system to achieve its goals;
3. ***«know how» flows*** are knowledges which are required by the system to achieve its goals;
4. ***«Want to do» flows*** are external requests to the system.

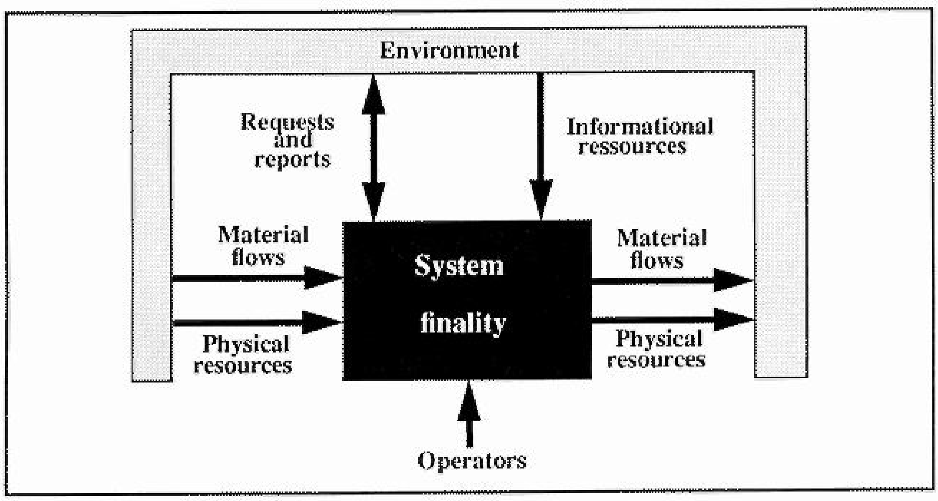

Figure 4. *functional box and its relations with environment*

Hereafter some examples of flows are presented, according to the cultivate function (Figure 3.) :

- To Do: fruits;
- Can Do: nutritive solution, waste;
- Know How : recycling and protection directives (chemical and biological data);
- Want to Do : growth set points (environment data).

In this example operators are plants and operative part elements.

2.1.3. Meta-rules for functionnal analysis

1. The finalities of activities are defined through flows.

That is to say that the meaning of an activity is defined through relations with its environment.

2. A control activity is associated with each level of process decomposition.

As our job is automation engineering, to model the manufacturing system is not sufficient.Our target is also to model the command system. Nature operators enable us to link control functions and manufacturing functions.

3. Two identical operators cannot be consecutive.

For example, let two functions which implement shape operators be consecutive. Then, there is at least one «to do» flow which is linking these two functions. Consequently, shape may be observed between these two functions. To be observed, shape must be located somewhere in time or space. That is not compatible with the initial hypothesis.

4. Only activities which implement shape operators can be split up.

On the one hand, the decomposition of an activity which implements a time (or space or nature) operator would be described by sub-activities which would implement different operators than the initial activity. That is not compatible with the finality of the initial activity.

On the other hand, the decomposition of an activity which implements a time (or space or nature) operator would be described by sub-activities which would implement the same operators as the initial activity. That is not compatible with rule 3.

5. ***Actuation and measurement is the lowest level of decomposition*** (Figure 5.).

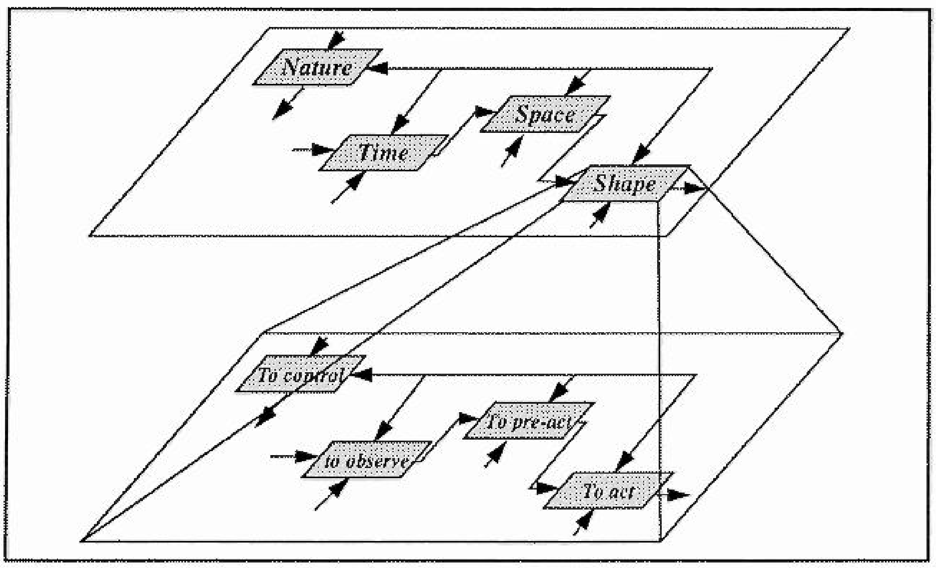

Figure 5. *Lowest level of decomposition*

The application of these rules will enable us to export knowledge from the functional model to the informational analysis and design step.

2.2. *informational analysis and design*

2.2.1. *Entity-relation ship formalism*

The informational modelling step uses the entity-relationship formalism as described in [AFN92].It is a neutral formalism that allows computer implementation without any ambiguity.

Basic concepts of entity-relationship formalism are entities and relations.

Entities are objects of the information system : concrete objects (pump, jack, ...) or abstract objects (response time, ...).

Relations are semantic links between objects. All relations are binary relations.
Relations and entities are characterized by attributes. Attributes are basic data which describe relations and entities.
Entities or relations which share a common nature, structure or definition are grouped together into classes. Each member of a class is called an instance.
Association (Figure 6.) is the basic relation of the entity-relationship formalism.

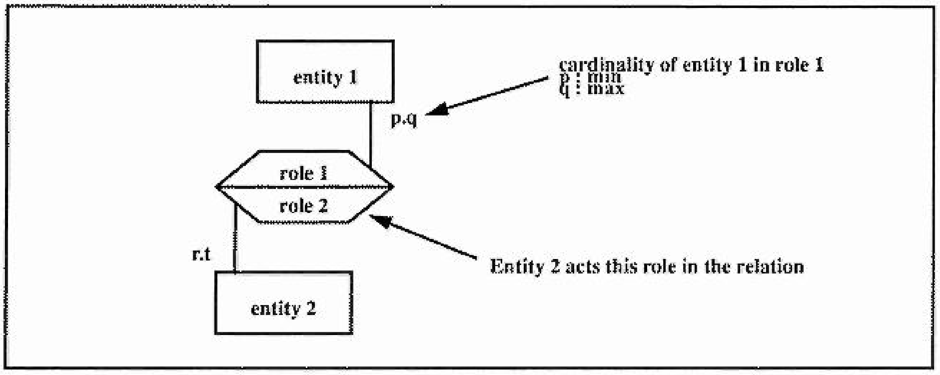

Figure 6. Association

A Specialization/Generalization relation between two classes is an inclusion relation. Classes have their own attributes and they inherit the relations and the attributes which have been defined at the upper-class level.
An aggregation is a structural relation which describes a kind of dependence of one entity to an other. The fact that an object belongs to another is one of the most frequent case.

2.2.2. *Links with functional analysis*

In respect to above mentioned meta-rules, each functional box of the functional model may be translated in entity-relation ship formalism as show (Figure 7.).

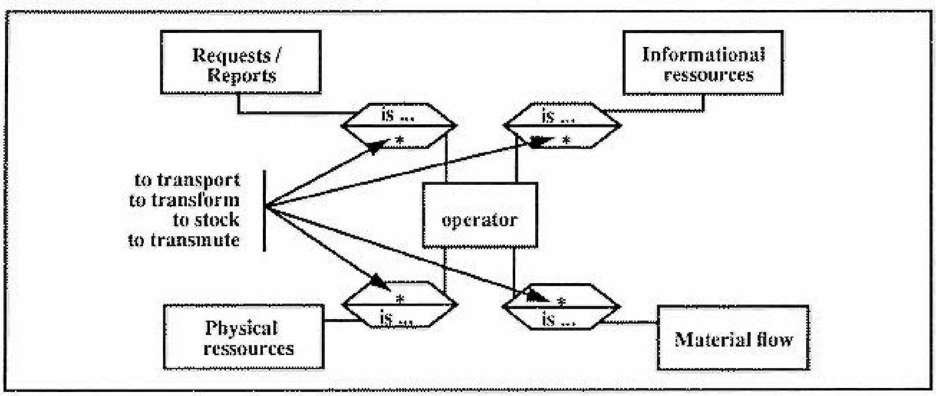

Figure 7. Basic translation of a functional box

At first the Operator provides the semantic of the association. The second time, the information system designer can choose the right verb according to the semantic of the operator and the manufacturing context.
Hereafter is an example, once more according to the cultivate function (Figure 3.)

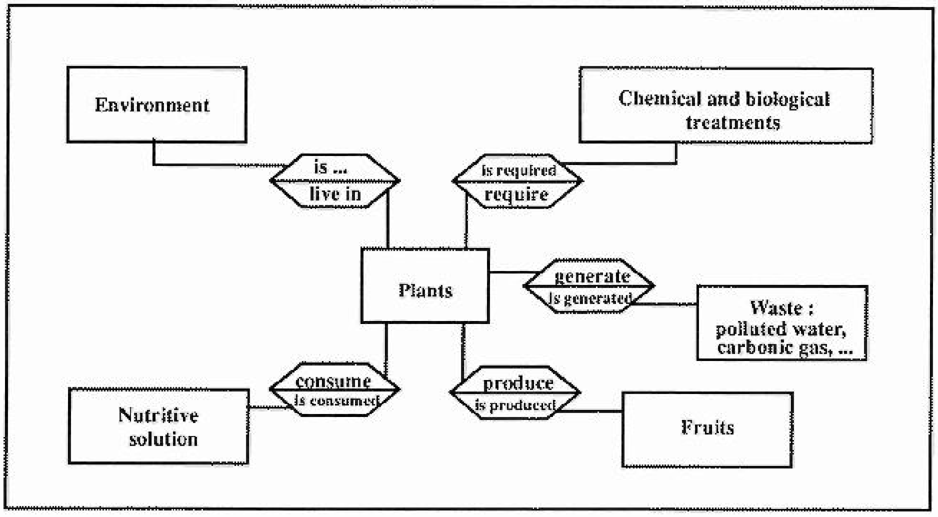

Figure 8. *Example of plant as a shape operator*

This translation of functional boxes provides the information system designer with associations.

Aggregation may be easily deduced from IDEF-0 hierarchy : decomposition of flows in sub-flows, decomposition of functions in sub-functions.For example, the environment is a combination of humidity, lighting, oxygen, carbonic gas, ... Then, it becomes the following example (Figure 9.):

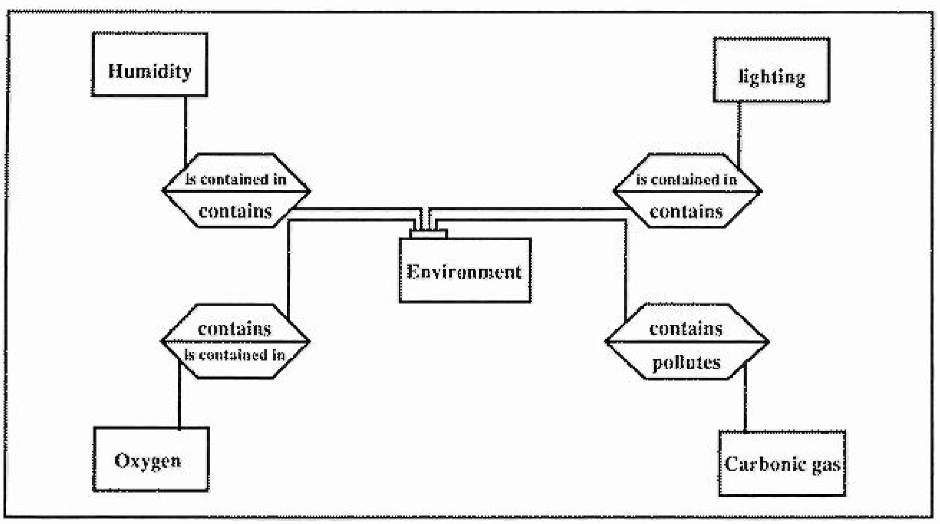

Figure 9. *An example of aggregation relation*

The linkage of the different parts of the informational model is then an obvious operation.

3. Conclusions

The present methodology had been applied to the prototyping of a CMMS architecture for a greenhouse. The results of the functional modelling step have been used to generate the skeleton of the technical management data base.

(Figure 10.) introduces the user interface of the prototype.

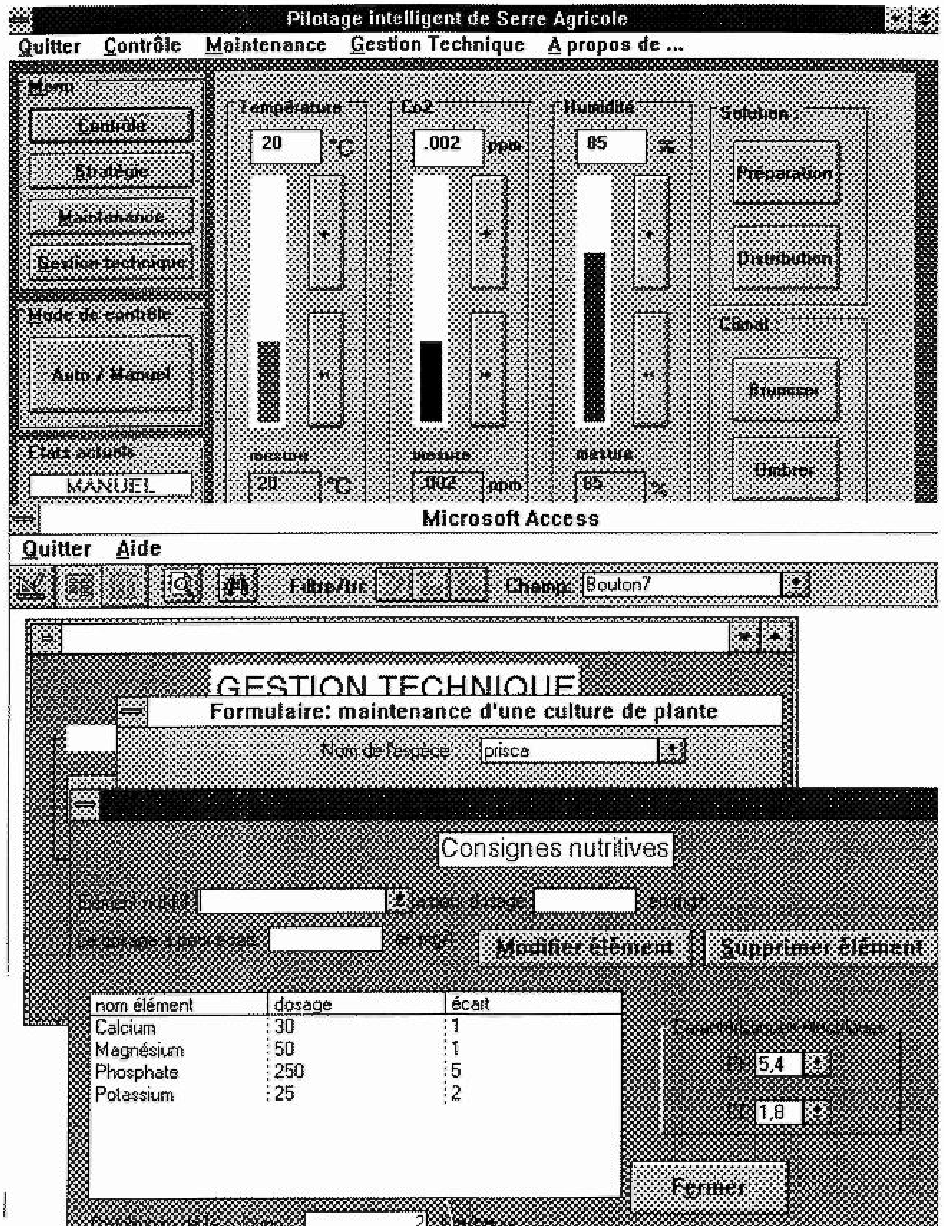

Figure 10. User interface of the prototype

Actuator is defined by [IUN92] as: "... the Achilles'heel of manufacturing systems ...". This new concept of Intelligent Actuation and Measurement requires:

- advanced data processing technologies to ensure the distribution of intelligence to level 0 equipment;
- new skill oriented methods to design, to implement and to operate Integrated Manufacturing Systems;
- new generical approaches based on the re-use of references models.

On the one hand, all the knowledge about the greenhouse system which has been acquired during functional and informational modelling steps will enable us to achieve our main goals :

- Intelligent control as regards different strategies : to minimize energy consumption, to optimize the growth of plants...
- Predictive maintenance as regards actuators, product behavioural modelling and climate simulation.

On the other hand, the gap between the poposed methodological approach and its software implementation is very short. This would be a further continuation of this work and a contribution to new skill oriented methods to design Integrated Manufacturing Systems.

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