NATURAL LANGUAGE INTERFACE FOR PROCESS CONTROL CENTERS

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Abstract. This paper presents a prototype of a friendly man–machine interface for control centers that uses a natural language (Spanish) processor. The vocabulary is adapted to the context of physical processes. The process is considered to be composed of components with associated physical and chemical magnitudes.

Keywords. Natural Language, Man–Machine Interfaces, Control Systems.

INTRODUCTION

In the majority of industrial process control systems most significant decisions are taken by control center operators. The reason for this is that completely automated systems are extremely problematic as pointed out by Martin and co-workers (1990) because *in situations where surprises can lead to critical situations and matters of life and death, responsible decisions cannot be left to such a systems alone. Instead final decisions must be left to people, because people have the ability to master unprecedented situations.* An appropiate man–machine interface is, therefore, a major concern in process control centers.

The need of friendly man–machine interfaces has been stressed in literature (Myers, 1989). It can be said that in general man–machine interfaces of control centers are quite friendly. Most of them use graphical screens to show the main process variables trough different screens or windows representing graphically different parts of the process. The variables which are not seen on graphical screens are normally shown in lists or tables. The operator communicates with the control system using functional or dedicated keyboards. The different elements are selected by scren pointing devices such as tracking balls, light pens, mouses etc.

Although, as has been mentioned before, the man–machine interfaces for control centers are quite friendly, they still need an extensive training period for operators. Other disadvantages of this type of man–machine interfaces is the great quantity of information, some of it irrelevant, they tend to present to the operator. Presenting the operators with too much information can be a problem as it will tend to shift their attention from the important issues at that moment. In reality, the amount of information given to the operator can normally be specified when configurating the system, but as it is not precisely known what information the operator is going to need in every situation, at this stage, practically every scren is configured to present more information than necessary, just in case it is needed.

Natural Language interfaces have been used succesfully for this purpose in other fields such as graphical management systems (Kasturi and co-workers, 1989) and information retrieve in stock market systems (Rodríguez, 1989). Natural language interfaces may be used in control systems to dialog with the operators, accepting commands and presenting information to them, in their natural languages. This may overcome some of the difficulties mentioned previously.

Another field of interest of natural languages processing is the explanation generation for expert systems. An expert system is a computer program that acts as an expert, that is, offering advice in most cases. An example of such an application can be found in (Kosy, 1989) where explanation in natural language are applied to financial modelling. As expert systems are a growing field in control centers, see for example (Rich and Venkatasubramanian, 1987) and (Niemann and co-workers, 1990), and some of then act as monitors offering advice or explaining the causes of a given situation, natural language processing may be, in general, of great interest as a tool for man–machine interfaces in control rooms.

This paper presents a prototype of a friendly man–machine interface for control centers that uses a natural language (Spanish) processor. The prototype presented uses a grammar restricted to control center enviroments and the vocabulary is adapted to the context of physical processes.

The paper is organized as follows: Section 2 introduces the main concepts of natural language processing. The knowledge bases needed for natural language processing in the control center enviroment are described in section 3. Section 4 is dedicated to describing the developed prototype. Dialog examples are presented in section 5 and finally some conclusions are made.

NATURAL LANGUAGE INTERFACES

There are two basic forms of natural language interfaces (NLI): those using the written form of human languages or those using the spoken form. The first ones use written sequences of words which are lexically, sintactically and semantically analized until their meaning is extracted. The second ones are more general and require a previous step in which the user's voice is transformed into a sequence of written words. In reality, this first step has to be done in cooperation with the analysis in order to get an efficient understanding. This first step is deeply related to signal processing and has specific problems concerning user dependency, continuous speech etc. There are a number of cards in the market that can recognize different numbers of words, are (not) speaker dependent and can (not) recognize continuous speech.

This paper centers on the problem of understanding the written language, which is common to both types of interfaces. The procedure for understanding a written sentence can be decomposed into the following tasks:

- Lexical analysis: The sentence is broken into words and each of them is checked in a dictionary where necessary information about them is obtained for the next step.
- Sintactical analysis: The grammatical correctness of the sentence is checked.
- Semantical analysis: The meaning of the sentence is extracted. It may occur that a sintactically correct phrase has no meaning. In general, a phrase is considered to be semantically correct if the corresponding control command can be constructed.

The two fundamental elements for understanding NL are the dictionary and the grammar. The dictionary contains all words that can be recognized by the interface and is necessary in the three phases of the analysis. The grammar is used in the sintactical and semantical analysis. In this last one, the compositionality principle of Frege is applied. This principle establishes that the meaning of the whole depends on the meaning of the parts that can be the same as the ones obtained in the sintactical analysis. In the case of control centers with NLI, the operators can express their commands to the control system in their language (or close to it). These commands will be analyzed, understood (translated to elementary commands to the control system) and processed as shown in Fig. 1.

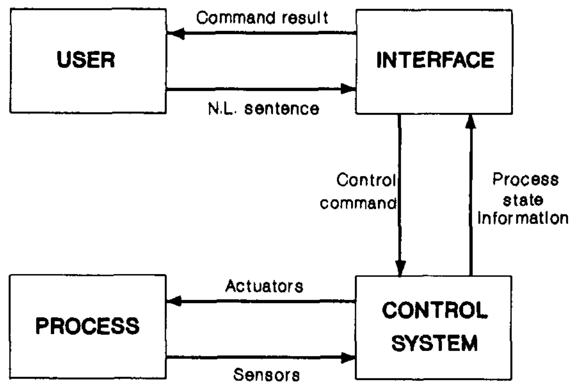

Fig. 1: NLI Block diagram

The operators do not have to know complicated Man-machine interfaces but will be able to use their natural languages referring to the process and to the related components without needing to remember precise names or labels for each of them.

KNOWLEDGE BASE

The necessary knowledge for the analysis is, on one hand, a linguistic knowledge and on the other knowledge about the process to be controlled. The first type of knowledge is general, whilst the second depends on the process at hand and has to be changed if the NLI is to be applied to another process.

Linguistic Knowledge. The linguistic knowledge includes the dictionary and the grammar. The dictionary is composed of all the words that the operator can use to communicate with the control system and is adapted to the context of physical processes. Thus the process is considered to be composed of components (pumps, tanks, pipes, ...) and elements (water, fuel, coolants, ...). There are also physical and chemical magnitudes associated to components and elements (level, flow, temperature, ...).

Words are entries for the dictionary and the output is their sintactical category and their associated meaning. For example, the word *valve* has the sintactical category *<noun>* and the associated meaning *<component,type valve>*. The word *open* has the sintactical category *<verb>* and the associated meaning *<order, type action, open>*.

The grammar is composed of a set of rules describing the language, that is describing how the correct phrases can be formed. The grammar is restricted to the environment of a control center. Two types of commands are recognised, those of action and of information. The first of these allows actions to be carried out on the process and the second one for information to be obtained about it. Gazdar and Mellish (1984) have shown that Recursive Transition Networks (RTN) have many advantages to process natural languages. The grammar used, expressed as a RTN, is shown in Fig. 2, where *S = Sentence, V = Verb, NP = Noun Phrase, DET = Determiner, PP = Prepositional Phrase, PREP = Preposition, R = Relational Clause, REL = Relative, CNJ = Conjunction, ID = Element Identification and ADJ = Adjective.*

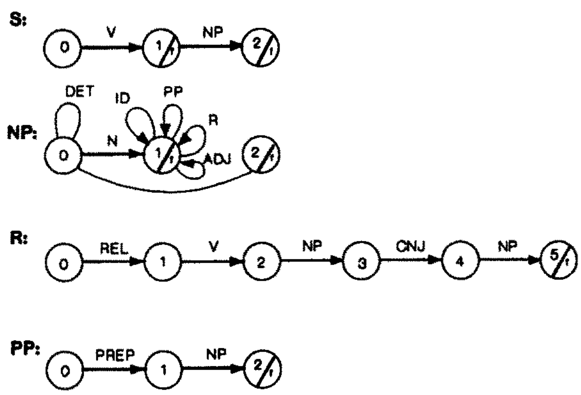

Fig. 2: Recursive Transition Network for the proposed grammar

This type of grammar simplifies the analysis, allowing real time processing, and can cope with most of the possible dialog between an operator and the control system.

Knowledge about the process. Knowledge about the process being controlled is necessary for extracting the meaning of the phrases introduced by the operators, that is, in order to perform a semantical analysis. The information about the process can be classified in the following way:

1. Fixed information:
   - Identification of Components. Each of the components must have a unique identifier and belongs to a class of components (valves, deposits, etc.).
   - Component functional dependencies. Components can be related by functional dependencies. That is, a valve can be the security valve of a system, a pump can be the filling pump of a deposit, etc.
   - Inclusion relationships. A component can be *a-part-of* a subsystem of the global system.
   - Process topology. Information about how the different components of the process are connected. In a hydraulic system, components are connected by pipes, whereas in an electrical network the busbars, switches and electric lines between substations are the connecting elements.
   - Actions on components. Not all actions on the different parts of the systems are valid. Each component needs specification about what valid actions can be performed on it.
2. Variable information.
   - Failures. A component or a system can be faulty. In this case certain actions can not be performed on it.
   - Measures. Corresponding to the variables where sensing devices which are read by the control systems have been installed.
   - State of the elements. The state of the elements depends on the actions taken previously and it will change with time.

The variable knowledge is kept fresh by the control system that reads the sensors located on the process as indicated in Fig. 3.

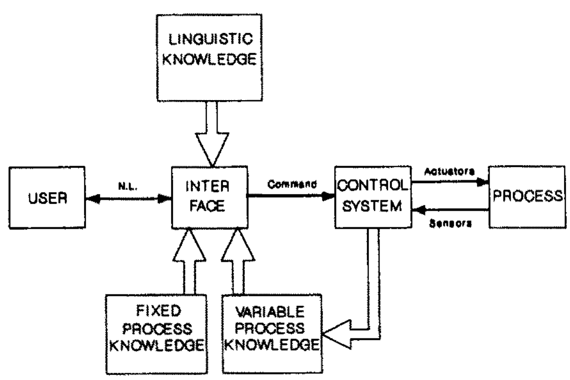

Fig. 3: Knowledge Bases diagram

The dialog of an operator with the control system is composed of phrases telling the control system to give some information, or phrases telling the control system to perform some action over the process. Most of the phrases can be classified under one of the following types:

- Direct orders over an element which is specified directly or by its relationship to other elements or systems: *abrir la válvula V4 (open valve V4)* or *abrir la válvula de entrada al deposito principal (open the inlet valve of the main deposit)*
- Direct orders over a set of elements. The set of elements is normally specified by a condition such as being a part of a certain system and belonging to a determined class of element, or being in a particular state: *Abrir todas las válvulas del sistema de refrigeración (open all valves of the refrigeration system).*
- Imprecise orders: *Abrir un poco la válvula de llenado del deposito principal (slightly open the filling valve of the main deposit).*
- Indirect orders (Goal orientated commands). Some orders require the execution of a series of elementary commands in order to be accomplished. The system should take into account if all the elements needed to carry out the order are in working condition.
- Order demanding information. This information can be in the data base as such or may need to be elaborated. An example of this last type of query could be demanding information about a measure that can be calculated from others or about the state of a system.

All these orders are not, in general, completely specified. In some cases, the phrases can be specified by using an anaphoric resolution method, in other cases, this is not possible and a dialog with the operator will be needed.

DEVELOPED PROTOTYPE

The ideas presented in the previous sections were implemented in a prototype of a NLI. The principal characteristics of the prototype presented are as follows:

- PROLOG (Clocksin and Mellish, 1984) was chosen as the programming language due to its being a declarative and recursive language, easy to use with symbols and structures and thus ideal for the development of natural language applications.
- The grammar used is the one described in the previous section which corresponds to a grammar defining a subset of the Spanish Language.
- The grammar is restricted to the environment of a control center. Two types of commands are recognised, those of action and of information. The first of these allows actions to be carried out on the process and the second one for information to be obtained about it.
- The vocabulary is adapted to the context of physical processes. Thus the process is considered to be composed of components (pumps, tanks, pipes, ...) and elements (water, fuel, coolants, ...). There are also physical and chemical magnitudes associated to components and elements (level, flow, temperature, ...).
- The prototype uses a procedure for anaphoric resolution of phrases which are not completely specified.

In order to illustrate how the NLI works consider that the operator has introduced a sentence such as: *Abre la válvula de entrada del depósito principal (Open the entry valve of the main deposit).*

A lexical analysis is first performed. That is, the sentence is broken into words and it is determined if all the words are in the dictionary and their sintactical category and meaning.

The second step is the sintactical analysis. A RTN parsing algorithm is used. Only phrases which are grammatically correct will pass this phase of the NLI. Part of the semantical analysis is done in this phase of the algorithm because, as it was indicated before, it is assumed that the sintactical analysis breaks the sentence into parts which are semantically significant.

The semantical analysis starts by instantiating the refered components to their respective values. This is accomplished in a bottom-up manner (Notice that the sintactical analysis breaks the sentence in a top-down way whilst the semantical analysis recomposes the phrase in the opposite direction). The sample phrase given above is transformed in the following manner:

Abre la válvula de entrada del depósito principal
(Open the entry valve of the main deposit)
ABRIR VALVULA ENTRADA DEPOSITO PRINCIPAL
ABRIR VALVULA ENTRADA DP
ABRIR V1

APPLICATION EXAMPLES

In order to illustrate the type of commands that the system is capable of processing and understanding, an example of a dialog with the NLI is presented. The control system and process referred to are simulated. The original dialog in Spanish is given in italics with the responses of the NLI in capital letters.

- *abrir la valvula V4*
  (open valve V4)

  -> *VALVULA V4 ABIERTA*
  (VALVE V4 OPEN)

- *abrir la valvula de entrada del deposito de agua caliente*
  (open entry valve of hot water tank)

  -> *VALVULA V5 ABIERTA*
  (VALVE V5 OPEN)

- *abrir la valvula que conecta la tuberia T2 con la tuberia T3*
  (open valve connecting pipe T2 to pipe T3)

  -> *VALVULA V4 ABIERTA*
  (VALVE V4 OPEN)

- *abrir la valvula que conecta las tuberias T2 y T3*
  (open valve connecting pipes T2 and T3)

  -> *VALVULA V4 ABIERTA*
  (VALVE V4 OPEN)

- *mostrar la temperatura del deposito DC*
  (show the temperature of tank DC)

  -> *EL VALOR DE LA MEDIDA DE TEMPERATURA EN DEPOSITO DC ES 25 C.*
  (THE VALUE OF THE TEMPERATURE MEASURE IN TANK DC IS 25 C.)

- *activar la bomba de recirculacion*
  (activate recirculation pump)

  -> *BOMBA BR ACTIVADA*
  (PUMP BR ACTIVATED)

- *activar la bomba de principal del circuito de recirculacion*
  (activate the main pump of the recirculation circuit)

  -> *BOMBA BR ACTIVADA*
  (PUMP BR ACTIVATED)

- *mostrar la temperatura de la tuberia que une el intercambiador de calor con con el deposito de agua caliente*
  (show the temperature of pipe joining the heat interchanger to the hot water tank)

  -> *EL VALOR DE LA MEDIDA DE TEMPERATURA EN TUBERIA T8 ES 30 C.*
  (THE VALUE OF THE TEMPERATURE MEASURE IN PIPE T8 IS 30 C.)

- *cerrar la valvula que comunica la bomba de recirculacion con el intercambiador de calor*
  (close valve connecting recirculation pump to heat interchanger)

  -> *VALVULA V8 CERRADA*
  (VALVE V4 CLOSED)

All these orders are correct and therefore executed. The following dialog examples correspond to sentences that cannot be executed for different reasons which are explained by the dialog itself.

- *mostrar el caudal de la tuberia principal de entrada del deposito de agua caliente*
  (show flow in main entry pipe of hot water tank)

  -> *NO EXISTE MEDIDA DE CAUDAL EN TUBERIA T3*
  (THERE IS NO FLOW MEASURE IN PIPE T3)

- *Abrir la valvula de salida del deposito principal*
  (open outlet valve of main tank)

  -> *EL COMPONENTE V16 ESTA EN ESTADO DEFECTUOSO*
  (COMPONENT V16 IS IN A FAULTY STATE)

- *abrir la valvula que une el intercambiador de calor con con el deposito de agua caliente*
  (open valve connecting the heat interchanger to the hot water tank)

  -> *NO EXISTE NINGUN COMPONENTE DE TIPO VALVULA ENTRE IC Y DC*
  (THERE ARE NOT ANY TYPE VALVE COMPONENTS BETWEEN IC AND DC)

- *abrir el deposito principal*
  (open the main tank)

  -> *LA ACCION ABRIR NO ES APLICABLE AL COMPONENTE DP*
  (OPEN ACTION CAN NOT BE APPLIED TO COMPONENT DP)

The following examples illustrate the anaphoric resolution procedure.

- *abrir la valvula de entrad al deposito principal*
  (open the entry valve of the main tank)

  -> *VALVULA V4 ABIERTA*
  (VALVE V4 OPEN)

  cierrala
  (close it)

  -> *VALVULA V4 CERRADA*
  (VALVE V4 CLOSED)

- *mostrar la temperatura del deposito principal*
  (show temperature of main tank)

  -> *EL VALOR DE LA MEDIDA DE TEMPERATURA EN DEPOSITO DP ES 25 C.*
  (THE VALUE OF THE TEMPERATURE MEASURE IN TANK DP IS 25 C.)

  mostrar el nivel
  (show level)

-> *EL VALOR DE LA MEDIDA DE NIVEL EN DEPOSITO DP ES 50 %*
(THE VALUE OF THE LEVEL MEASURE IN TANK DP IS 50 %)

cierra la valvula de entrada
(close entry valve)

-> *VALVULA V4 CERRADA*
(VALVE V4 CLOSED)

CONCLUSIONS

A model for a natural language interface of control centers has been proposed. A prototype of a NLI has been developed in PROLOG. The prototype accepts Spanish sentences corresponding to most possible dialogs between operators and control centers. The NLI could be greatly enhanced by introducing other techniques such as temporal reasoning in the explanation mechanism.

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