Fuzzy Diagnose Microcontroller Based System for Air Quality Surveillance

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Abstract

Current work deals with the design of a local unit, micro-controller based to acquire signals from a set of sensors and locally diagnose on the air quality. The local unit permits the interface with standards atmospheric and meteorological sensors, as well as the communication with a central unit by message passing protocol, via GSM. A fuzzy inference system has been developed to perform the approximate reasoning process performed by a human being, based on the perception of the environment conditions. The decision algorithm is based on a performance criterion, the one that forces the emergence of the pollution level with minimum communication and maximum environment safety. The processes running at the local unit have been modularly designed within the frame of a Client/Server architecture to ease its gradual growing and maintenance. The local unit bi-directionally communicates with several central units that record and visualize stationary data and acts at the reception of an emergency message. Communication is performed either following a remotely programmed pattern, event based or under the user demand.

I. INTRODUCTION

The constant increase in world population has led to an ever growth in the consumption of resources and energy all over the world, that entails an enormous environment degradation. The term sustainability, full fashion nowadays, has emerged as a concept to summarize the need to maintain growth with minimal environment degradation [1].

Many industrial sites have been built, in the last decades, too close to either urban or suburban environments. Some of them are thickly populated with small and medium-sized companies with a high temporarily in their location and production. This gives rise to the appearance of a great variety of air pollutants, which are difficult to pursue and localize.

Nowadays, pollution prevention technologies appear as one of the pre-conditions that have to be met to get sustainability into reality [2]. The basic intention behind the emphasis on pollution prevention is that, while pollution control is necessary to deal with contamination that has already occurred, the prevention of further pollution is of major relevance. A dedicated commitment to co-ordinate local, regional and global scale atmospheric management is now required for future environmentally sustainable development [3].

Most of the already existing contaminants surveillance nets are neither concerned with real time diagnosis and control of the air quality or with the localization of the potential emission sources. This lack of research is mainly due to the exhaustive and instantaneous data analysis and interpretation required for most decision-making processes. Nowadays, the decrease in price of computer systems associated to their ever-higher performances open a new scenario to the development of more complex remote surveillance systems.

Present work proposes a low-cost processing system, microcontroller based, that offers broader reasoning and communication capabilities to make local decisions on either perceptual restrictions or on the frequency and type of commands to be transmitted. To deal with the uncertainty and the non-linearity of the surveillance system, a fuzzy rule base approach has been investigated with the aid of an application already developed at the IAI-CSIC, namely FuzzyShell [4]. The rules base encapsulates the approximate reasoning processes performed by a human operator who makes appropriate decisions based upon the signal values displayed at the monitoring system.

II. THE LOCAL UNIT

The objective of current environment net is the surveillance and control of the air quality in an urban industrial site, Arganda del Rey, close to Madrid. The surveillance being accomplished by means of the pre-processing of the sensor signals performed on a set of local units conveniently distributed in the industrial site. A fully documented diagnosis and the consequent control actions will be derived at the central unit that records the sensor unit's history in a GIS format database.

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The local unit has been designed keeping in mind flexibility, robustness and modularity, to be configured according to both the urban industrial site needs and the European Union regulations. The sensors and the surveillance requirements differ from one site to the other, as they depend on the type of industries, the local weather conditions and the traffic present in the zone. All of them point to tentative pollutant emissions to the atmosphere from tentative locations. The flexibility of the Local Unit is mainly related to the possibility of easily add or remove sensors with minimum processing disturbances and the capability to modify the parameters, variables and decision rules in the implemented fuzzy algorithms.

Each local unit offers a bi-directional communication protocol to transmit pollution data and detected emergencies to a remote central unit, usually located in a Civil Service Office, and to receive the configuration parameters selected by the operator, Fig. 1. The communication system has a mixed character, as the local unit contemplates different communication codes with the central unit (GSM, Trunking, PMR, MODEM) whether or not they simultaneously operate.

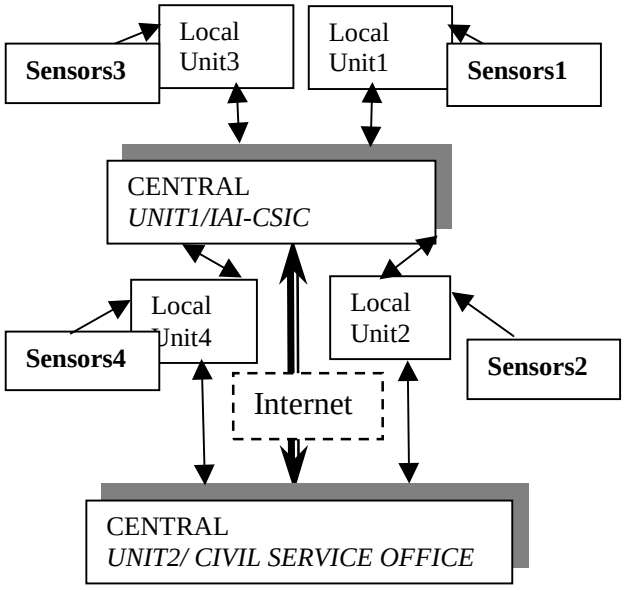

Fig. 1. Surveillance net: 2 central and 4 local units

The acquisition and processing local unit has been designed based on a RISC micro-controller with 32-bit internal and 8/16-bits external data bus, Fig. 2.

The micro-controller is structurally composed of 4 MB RAM, 512 KB EEPROM, 32 KB NV RAM, four serial ports, a real time clock, 8 analog input channels and 20 digital input / output ports. Memory can be expanded up to 8 MB RAM. Twelve of twenty digital ports are used as a pulse generator or PWM outputs. The software application is based on a developed drivers library. Each driver is associated to a specific interface (serial ports, digital input / output, analog input channel, etc) and a kernel is in charge of scheduling the drivers CPU time consumption.

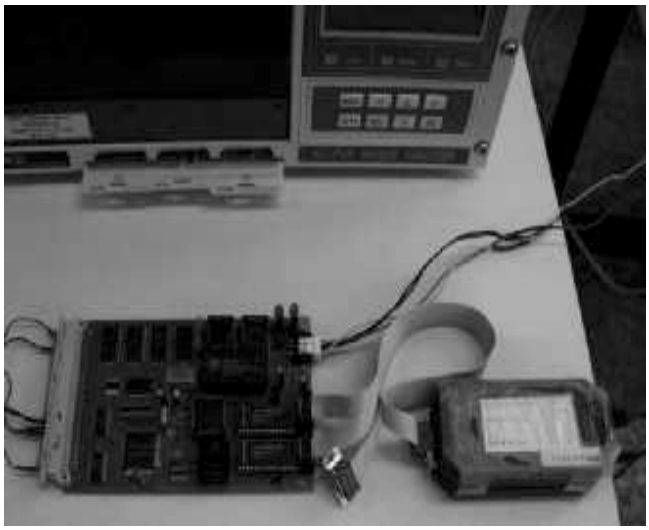

Fig. 2. Local unit micro-controller based prototype, GSM phone, and SO2 sensor.

Conventional processor boards, usually employed in acquisition and control applications as current one, include an operating system that is designed to fulfill unspecific users exigencies. Nevertheless, in current application the software and hardware requirements are very specific and would only require a minimal part of the whole functionality offered by the conventional processing systems. On the other hand, the more generic the systems are, the more they are functional and ease to fail. Conversely, a system based on a micro-controller can be designed with the same functionality that a general purpose one, but it can be developed to perform more robustly reducing the possibility of failures. In addition, the variety of input and output interfaces offered nowadays by micro-controllers systems, greatly facilitates their connection to other subsystems. This last assessment greatly differentiate micro-controllers from the generic processing systems, whose connection interfaces are sketched according to the system design and it is extremely complex to improve later on their performances, such as: the signals acquisition frequency

III. FUZZY DECISION SYSTEM

Fuzzy logic has successfully been applied in decision-making, classification and control processes that can be described by a set of linguistic expressions due to the difficulty to derive an analytical model. Fuzzy sets appropriately model the uncertainty inherent to human approximate reasoning, by embodying his knowledge in a set of linguistic expressions that manage words instead of numeric expressions [5]. Fuzzy logic reasoning systems have the discriminating ability of an expert forecaster that

understands and interprets the information gathered by multiple sensors [6], [7], [8], [9].

The fuzzyfication of the instantaneous sensor inputs, the inference process and the defuzzyfication algorithms are performed with a set of fuzzy libraries, developed to run under the developed micro-controller board. They are the components of a new version of the FuzzyShell environment [4], already used in control applications with conventional PC based processing systems. A preliminary fuzzy rules base, with two inputs and two output, is proposed to derive both, the variation in sensor signal acquisition rate at the local unit and the alert level to be transmitted to the central unit whenever the alert threshold for the protection of human health is exceeded, either hourly or daily.

A. Input Variables

The input variables are the wind speed (WSPEED) and the concentration of sulfur dioxide (SO2).

B. Output variables

The output variables are both the sampling rate of the wind speed signal (SRATE_WSPEED) and the alert level of wind speed (ALERT_WSPEED).

On the other hand, there is the sampling rate of SO2 concentration signal (SRATE_SO2) to be addressed to the local unit and the alert level for the SO2 concentration. (ALERT_SO2), Fig. 3.

C. Rules bases

TABLE I
RULES BASE 1 AND RULES BASE 2

		SO2		
	SRATE_WSPEED **ALERT_WSPEED**	**LOW**	**MEDIUM**	**HIGH**
WSPEED	SHORT	SMALL NONE	SMALL NONE	NORMAL NONE
	REGULAR	NORMAL NONE	NORMAL MODERATE	GREAT EXTREME
	ELEVATED	NORMAL MODERATE	GREAT EXTREME	GREAT EXTREME

		SO2		
	SRATE_SO2 **ALERT_SO2**	**LOW**	**MEDIUM**	**HIGH**
WSPEED	SHORT	SMALL NONE	NORMAL MODERATE	GREAT EXTREME
	REGULAR	SMALL NONE	NORMAL EXTREME	GREAT EXTREME
	ELEVATED	SMALL NONE	NORMAL EXTREME	GREAT EXTREME

Defuzzification is performed through the gravity centre algorithm: $y = \int_Y \mu_0(y) y dy \Big/ \int_Y dy$

Where the output variable y represents either: SRATE_WSPEED, ALERT_WSPEED, SRATE_SO2, or ALERT_SO2, see TABLE I.

In air ambient, the limit values and alert threshold for sulfur dioxide are as follow: a) {Hourly/Daily} limit value for the protection of human health, {350/125} microgr/m3, not to be exceeded more than {24/3} times a calendar year, b) Alert threshold 500 microgr/m3 over 3 consecutive hours at locations representative of air quality over at least 100 km2 or an entire zone, whichever is the smaller [10].

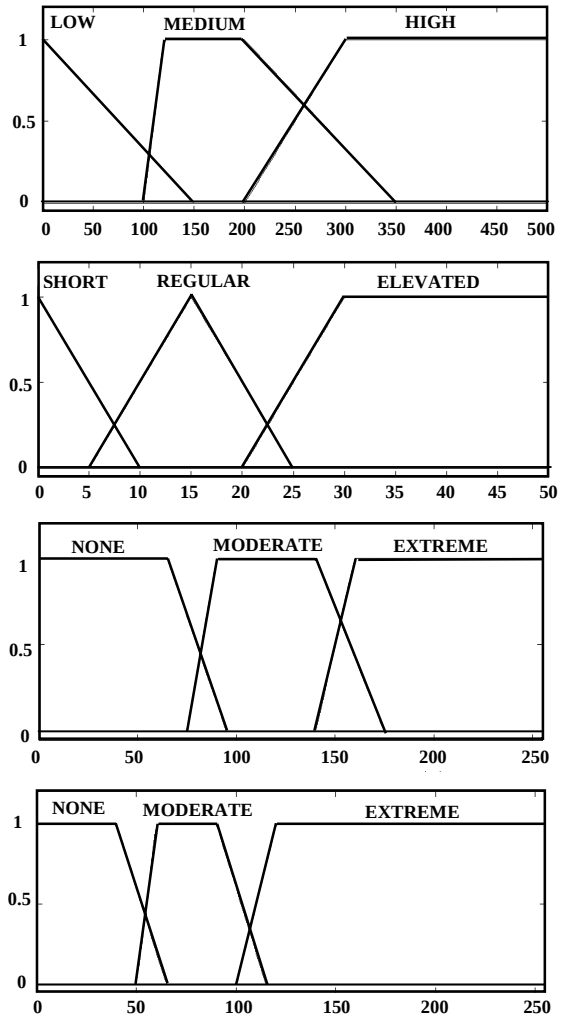

Fig. 3. Membership functions of both the two inputs {SO2,WSPEED } and the two outputs { SRATE_SO2, ALERT_SO2} of Rule Base2.

IV. RESULTS

The control surface, over the whole universe of discourse of the input variables, has been calculated for each of the output variables. Two surfaces are displayed in Fig. 4. Membership function values are tuned according to an expert

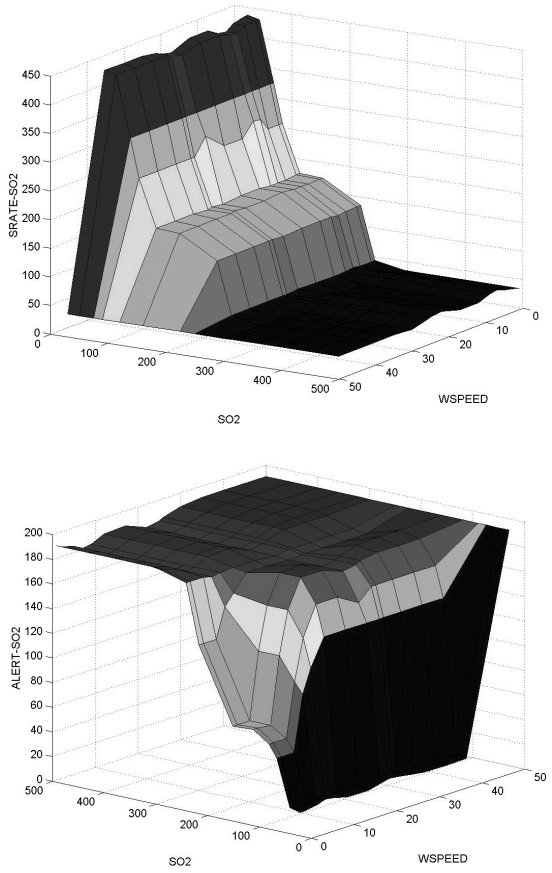

Fig. 4. - Control Surfaces for SRATE_SO2 and ALERT_SO2.

to closely reproduce the human recommendations and actions facing a wide range of input conditions all over the universe of discourse of the input variables. The control cycle of the fuzzy diagnose system is about a few microseconds. well below the real time requirements.

V. CONCLUSIONS

Micro-controller based systems offer some advantages in contrast to more conventional approaches based on general purpose microprocessors, such as: a) Lower cost, once the first prototype is achieved, b) User requirements are carefully considered at the design period, so that the specific micro-controller characteristics are accounted for, to benefit the application with improvements at the design stage and c) The acquisition and maintenance cost of the Local Unit once manufactured, would be in a factor of hundred with respect to conventional microprocessor systems.

The proposed fuzzy approach appropriately matches the pollutant prevention expert policy. The system offer the characteristics of flexibility, robustness and modularity required for a system that has to grow incrementally. Its scalability has to be proved, further on, with the integration of more sensor inputs to the Local Unit.

The Client/Server architecture developed is a good framework to deal with the distribution of processes either intra Local Units or inter Local and Central Units. It also allows for an ease development of processes by different researches in order to test different reasoning or communication algorithms. Modules can be interchanged with a great facility. Present work is a preliminary and interdisciplinary research in Environmental Science and Distributed Artificial Intelligence.

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