USE OF LABVIEW AS LOCAL SUPERVISION FOR THE LEP COOLING AND VENTILATION CONTROL SYSTEM.

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INTRODUCTION

In the 80's the LEP/CV group was in charge of designing and installing the cooling, ventilation and fire security equipment of LEP. Since the start-up in 1987, the accelerator's performance has increased steadily and frequent upgrades have been needed. The circumference of the machine and the variety of technologies involved make all systems very large and complex.

The ventilation process provides all underground zones (tunnel, technical zones, experimental areas) and some of the critical surface buildings with conditioned air. It also provides local air cooling for electronics and technical rooms as well as pressurisation of safe areas. Over 1.5 million cubic meters of air are processed every hour in 264 air handling units. The cooling and dehumidification functions are based on chilled water technology. The water is cooled by eight plants using centrifugal and reciprocating chillers. When mixed it is also used at higher temperature (16°C) for electronic crate cooling. The heat generated by the process is recovered in the air handling units, and the excess is discarded in a primary water loop. Evaporative cooling towers with a total capacity of 220 MW dissipate the heat from these circuits and from several others such as the demineralized water loops designed to cool magnets, vacuum chambers, accelerating cavities and experimental facilities. Finally, pumping stations supply all sites with water for cooling purposes and for fire hydrants. The underground fire security system sends alarms to the central control room, interacts with other processes in case of emergency and provides extinguishing facilities in the critical areas. New systems have been added every year since the initial design. Among the most recent ones: compressed air generation for the cryogenic processes, desiccant cooling, logging of environmental parameters for LEP Energy calibration purposes.

CONTROLS

In such a large and distributed system the controls architecture had to integrate turnkey equipment built by many manufacturers. Matching both the control strategy chosen for the rest of the accelerator and the standards used by industrial control suppliers was not an easy task. A clear limit of supply was set by asking the contractor to deliver fully functional equipment controlled by a Programmable Logic Controller (PLC), with an RS232 link using a well-defined protocol to communicate with the outside world. All processes were therefore self-sufficient and can communicate with other equipment and the main Technical Control Room (TCR) via the LEP service network. Following the equitable purchasing policy, CERN could not impose a PLC brand, and we ended up having most available models on the market at the time (ABB, Siemens, Télémécanique, Texas Instruments,...). We did not think this diversity to be an obstacle, since each contractor had to supply a local supervision console with a user friendly interface. The link between the PLC cluster and the LEP network was done at CERN using an ECA (Equipment Control Assembly - G64 crate). A PC running LynxOS was chosen as gateway to the general services Token Ring network of LEP. The TCR used Appollos that were later upgraded to HP 700 series workstations.

At the last minute, the local supervision consoles were removed from the contracts for budgetary reasons, except for the chilled water process in four points among eight. This decision made commissioning and maintenance more difficult. Only limited investigation tools were left at both ends of the data chain: the yet not fully operational central TCR system and the programming consoles. On one hand the information is event driven, summarised for efficient use by the non-specialised operators, who in case of a problem try to restart the equipment and then call the experts if necessary. On the other hand information is overwhelming and hard to interpret.

NEED FOR LOCAL SUPERVISION

The requirements for operation and maintenance were quite different from the ones of the TCR. Standard packages do not include features such as trend and failure analysis, historical behaviour and process optimisation.

The need for a specific tool became crucial since the performance of LEP was increasing rapidly, requiring better control of the environmental parameters of the machine. The primary duties of cooling, heating and dehumidifying have been evolving towards a very tight control of all environmental parameters. In the meantime computing was undertaking major improvements, and one could legitimately expect process supervision to be user friendly, to provide the user with a uniform man-machine interface (MMI) across all processes, and to be easily expandable.

After a comprehensive analysis of the market, we came to the conclusion that PLC manufacturers kept selling supervision systems that were closed, expensive and platform dependant. More suitable for our application were general purpose supervision tools such as Factory Link, LabVIEW, In Touch, PC Vue, … which have key advantages: easy connection to a wide range of PLC's, availability on generic platforms and operating systems, and lower price.

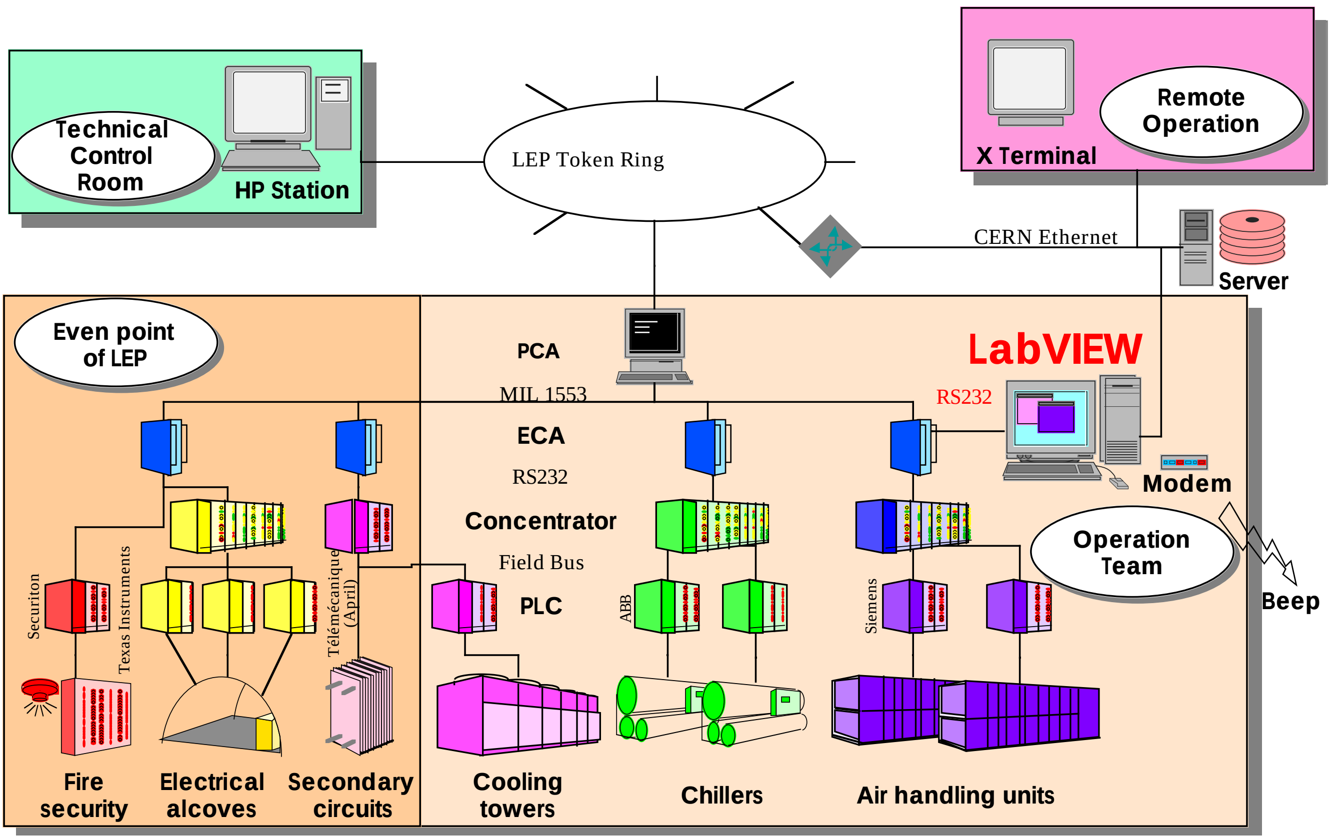
CHOICE OF LABVIEW

The co-ordination of industrial controls is organised at CERN [1], and in the fall of 1992 when a demonstration of LabVIEW took place we thought this product would be most suitable for our purpose.

The wide acceptance of LabVIEW, its cross platform portability and its low cost influenced our choice. Even though LabView was first presented as a laboratory oriented package, it has evolved towards being a general purpose compiler that includes many advanced libraries and still remains usable for simple tasks by a non-programmer.

At the time of the last ICALEPCS conference, in Berlin, our software and hardware choices were settled. Since then, the system has been developed and become operational. The present paper presents our first remarks and draws some conclusions after several months of continuous operation. Although certainly subject to future enhancements, it has already proved to be an invaluable tool for monitoring the cooling and ventilation processes of LEP.

INTEGRATION IN THE EXISTING CONTROL ARCHITECTURE



Existing controls

The HVAC controls for LEP were designed in the 80's, but they follow closely what is now commonly accepted as the standard architecture.

Since most of our systems were industrial in type, we used the ECAs as bridges between the RS232 coming from the PLC's supervisor and the Mil1553 bus. To guaranty fast data access through the network, each ECA keeps in memory an updated image of the data contained in its dependent supervisors. It also translates the commands issued by the control room into the proprietary protocols used by PLCs (JBUS, XCOM, 3964).

Connection of the local supervision

Three solutions were considered for the integration of the local supervision console into the existing control architecture: connection to the PLC field buses (supervisor), to the Mil1553 (ECA), or to the token ring (PCA).

The first solution delivered excellent performance but required the installation of new cables, and imposed the coding of all PLC drivers within LabVIEW.

The simplicity of the second solution was very attractive. We immediately thought of using an ECA as an RS232 - Mil1553 bridge. The ventilation ECA matched well since it had a spare serial port, could handle the additional load, and was located in a convenient area. We also decided to keep the syntax and format used by Mil1553.

The third alternative inserted another layer with no gain over the second solution.

DEVELOPMENT OF THE SUPERVISION PROGRAM

Data handling

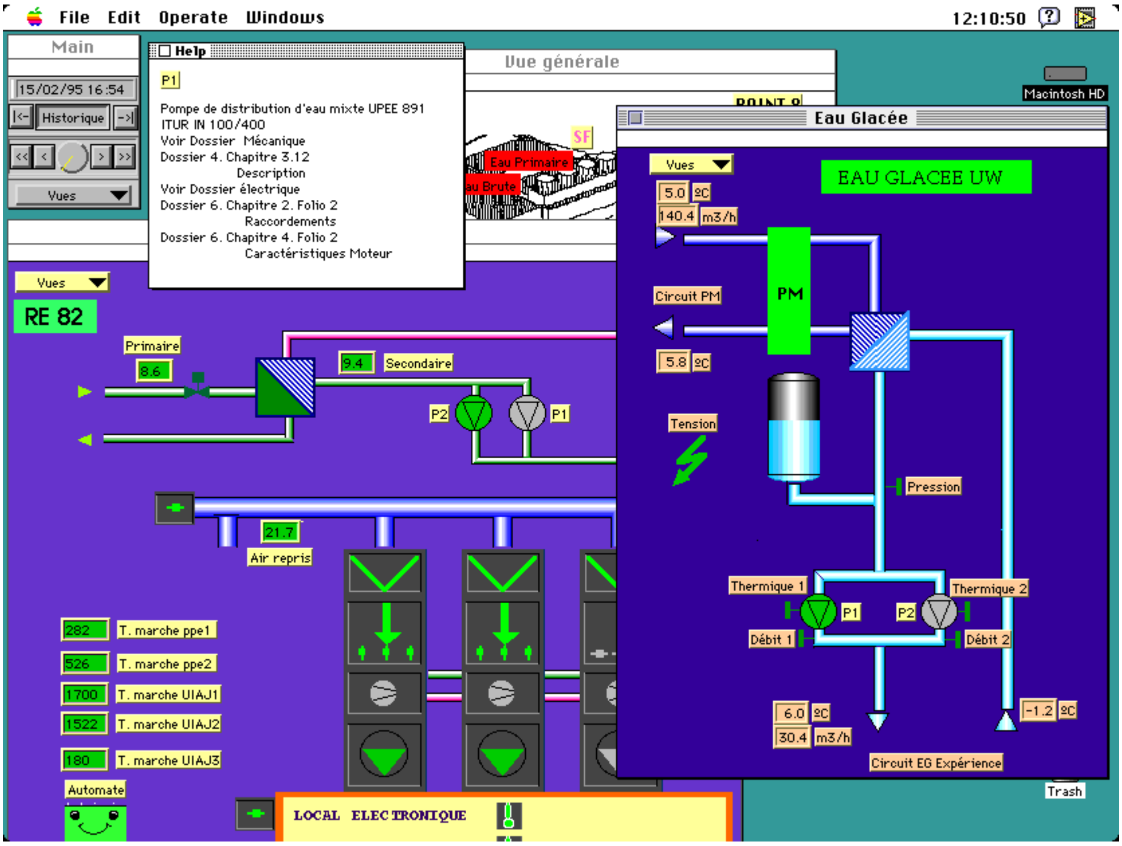
All data are read in 16 bit format through the serial port and stored in memory every thirty seconds, which is more than adequate for our slow processes. The data being stored locally, all kinds of processing were possible. The purpose of our application being to facilitate the work of the operation and maintenance teams, weekly meetings allowed examination of the design and its matching to the real needs.

We were urged to design a supervision console based on the traditional animated synoptics representing the status of the controlled equipment in real time, coupled with alarm printing. This was quite simple, since LabVIEW contains many graphing tools and imports any image created by drawing programs. The lack of a technical symbol library was not a real drawback, and we rapidly created our own.

However, we soon realised that implementing this concept developed primarily for central control rooms did not fit our needs. Trends, historical behaviour of the equipment and failure analysis were missing features that were important to us. Hence we added a one hour ring buffer to navigate back and forth in time to replay specific sequences, as with a video cassette recorder. This system was praised and we soon were asked to increase its capacity to days, then months and finally years. We eventually replaced the ring buffer approach by an extensive data handling program.

Data are stored into daily files constituted of 1440 fixed length records filled minute by minute. This rigid scheme minimises access time but is not space efficient. Consequently, we use a compression utility (Stuffit) to automatically recover disk space every night and transfer the stuffed file to a file server for archiving. We also use a cache mechanism to limit the wait induced by file expansion. This technique is worth the effort since the compression ratio exceeds 95%.

Synoptics

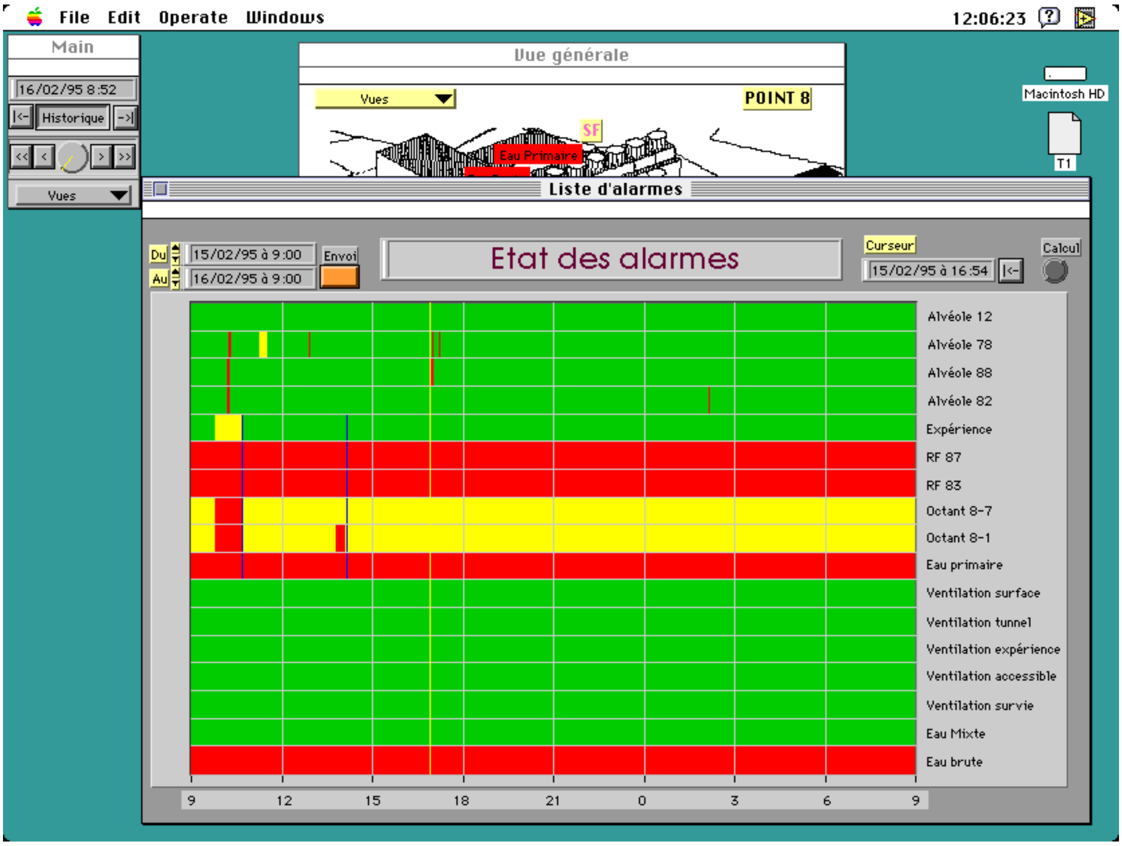


The bulk of any supervision system consists of animated synoptics. We had to develop hundreds of them for our application. They are organised in a tree structure, from overall snapshot to zooms on details, but they are nonetheless completely independent. Each synoptic is a self running program that gets its data from a global variable, and thus a bogus code cannot corrupt the rest of the application. This deliberate choice allowed several persons to develop simultaneously without constraint.

A template was first created. It is an empty front panel associated with computer code that contains both a synchronised loop triggered by the main program when new data arrive and a fast loop handling button and menu events. In addition, we developed a virtual instrument (VI) library containing standard subroutines that perform often used bit array operations, data conversion, threshold detection, …

After a one week course the persons in charge of the processes, who are not programmers, were able to design the user's interface and its associated logic. The only challenge was to enforce a common strategy to obtain a uniform MMI for all processes. This was done during "lively" weekly meetings.

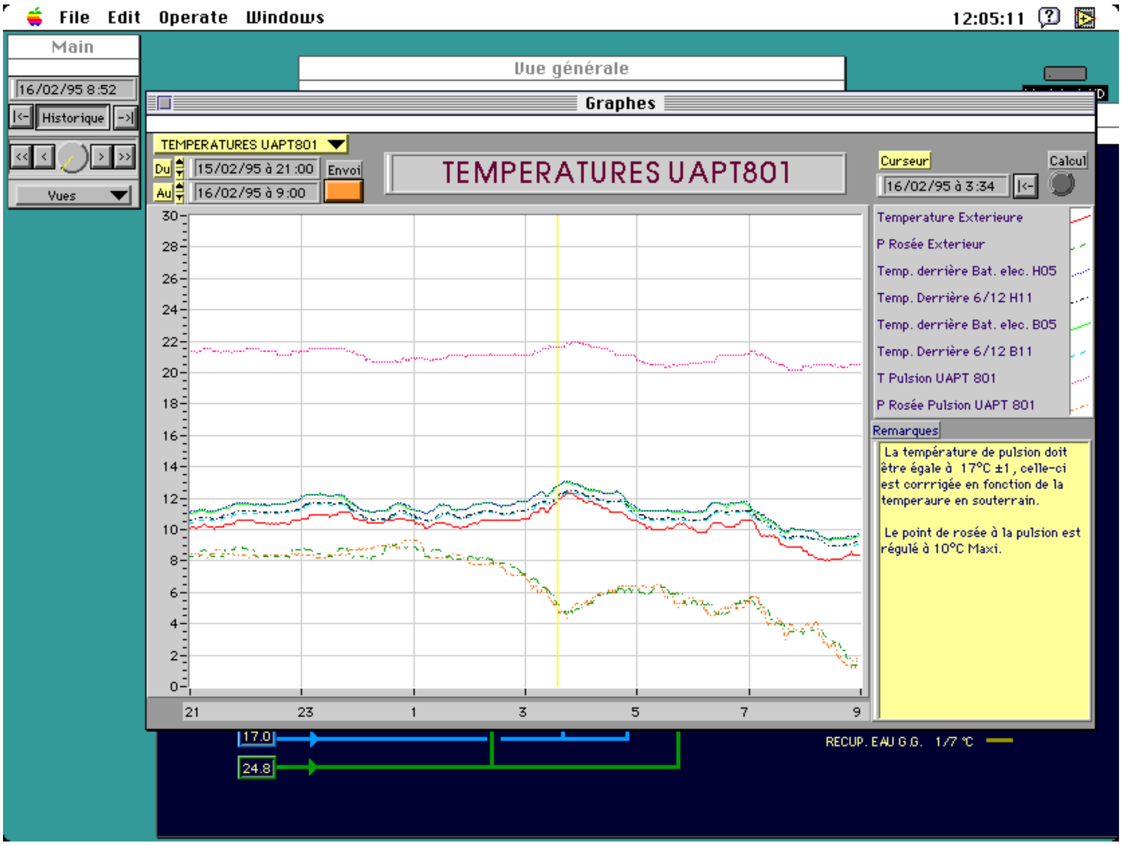
Alarm system



First, we decided to print alarm messages on paper as they occurred. Once again practice showed that this traditional technique was not adequate for our use, since alarm lists were inevitably discarded or lost. We then decided to store the messages for on-demand printing, but users complained that when a general alarm occurred the system would spill hundreds of them simultaneously, losing the chronology. The initial problem, such as a 400 kV power supply failure, would be hidden. Instead, we created an alarm chart showing the status of each system versus time. At a glance, it is easy to check that systems have performed well during the previous few hours. By the means of a navigation cursor it is possible to determine the exact time of a fault, and then call directly the appropriate synoptic and use the VCR navigation tool to replay and analyse the animated sequence. This chart is now the main investigation tool for our maintenance crews.

During business hours people are present on the points of LEP, so we decided to install modems that automatically page a member of the maintenance team in case of an alarm. We can generally intervene before a major failure.

Charts



At the beginning of the project charting capabilities had a low priority on the wish list, but after a year of operation they represent the most popular feature. It is now accepted that a good curve is worth more than a thousand alarms. Due to insistent requests we even had to trade our black and white printers for colour ones.

In most supervision packages the designer must define a limited set of historical values. In contrast our system can plot any data for any period of time since everything is stored on the hard disk. When calling the standard graph module the synoptic passes a variable containing all information: offset, scaling factors, legend, … . This yields the greatest flexibility.

Data and alarm generation

Operators often complained because alarms would trigger emergency stops without prior warning. The absence of pre-alarms was unfortunate, but was justified by the limited amount of memory available on our PLC. Similarly, useful calculations such as power usage and thermal balance were never performed. We added a module in our program for this unique purpose.

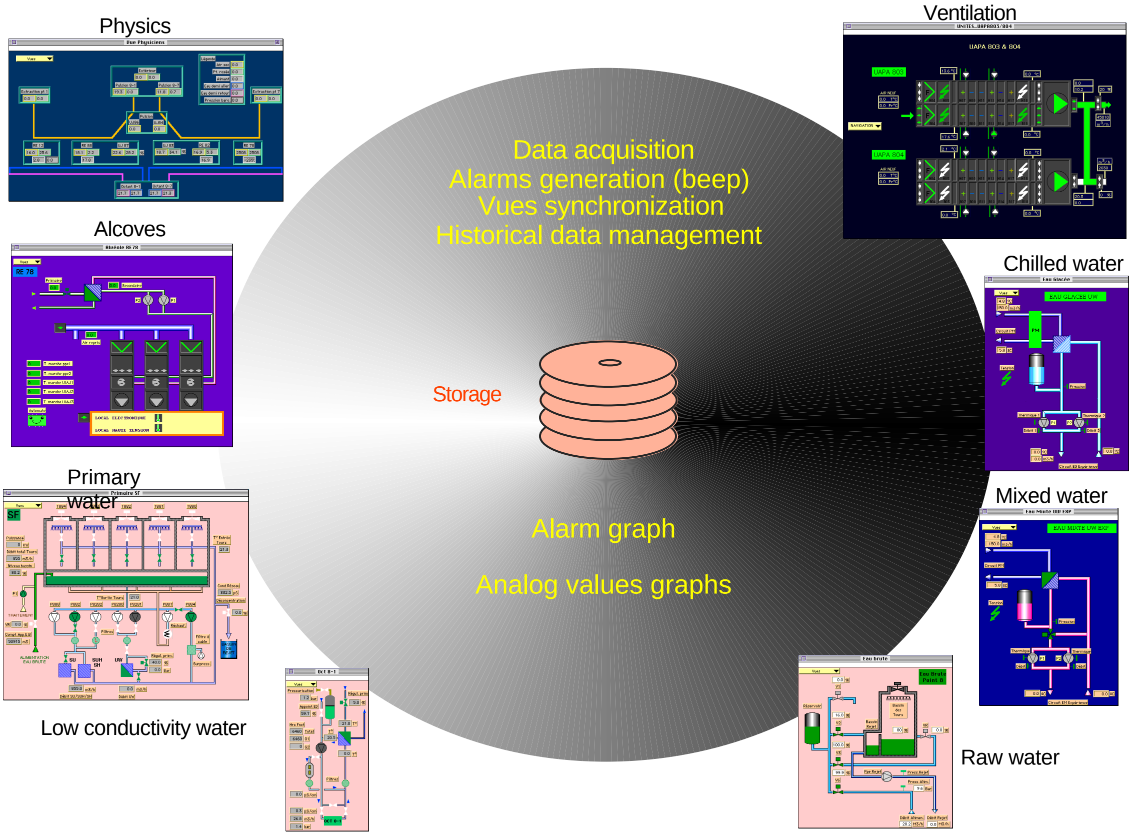
Overall system optimisation

The HVAC systems are physically interdependent and the accelerator relies on them. For example, a failure of the primary water loop soon provokes the interruption of all equipment cooling, leading to beam loss. In such a context it was unfortunate that the interactions between control systems remained limited.

A first attempt at such an interconnection was made with the dipole temperature control. We made a permanent connection to the magnet temperature measurements, and were then able to adjust the demineralized water loop set points as a function of dipole temperature to guaranty a stability better than ±0.2°C. This application demonstrated LabVIEW's remarkable flexibility in an accelerator environment.

This approach could now be extrapolated to other processes for overall system optimisation.

DEVELOPMENT ORGANISATION



Since the start of the project we have been meeting on a weekly basis. We first discussed data acquisition, communication protocol and hardware characteristics. Rapidly the overall supervision structure was defined, and we could start the design of the synoptics. We thought that the MMI definition would be an easy task, but we soon discovered that colours, symbols and naming conventions could generate emotional debates. Compromises were eventually obtained on almost everything, sometimes painfully, but we never reached an agreement on details like background colour …

Later we started inviting people of the maintenance team, who gave us valuable feedback. They played an important role in testing beta versions and criticising the design. Their sensible remarks often influenced the course of the development. However even the earliest versions allowed one to diagnose faults in the HVAC systems.

Every time we set-up a point of LEP, we would invite its maintenance team to the meetings. Gradually the topics were more oriented towards the exploitation of the installations. Today the meetings are entirely dedicated to the analysis of the past week's history and the refinement of the intervention strategy.

COSTS AND RESOURCES

The hardware acquisitions consisted of Macintosh Quadra 800 machines (16 MB RAM, 240 MB HD) equipped with 17" monitors, eight ink-jet printers, four modems, and a 1 GB hard disk for archiving.

After an initial payment of $2000, the use of LabVIEW only required the payment of a $500 annual fee to benefit from the maintenance and support program. Runtime systems were free of charge.

The direct human resources represented two man-years, but the induced work was substantial. Process tuning, PLC program debugging and systems modification were not negligible tasks. We should stress that this work was accomplished in addition to people's normal duties and that no extra resources were used.

ESTIMATION OF THE PAYOFF

Debugging

The local supervision was a mere prototype when we first observed some unstable cooling system operation. We found that in some PLCs, A/D converters would poorly truncate analog values. We also discovered that some initialisation subroutines were causing unreliable start-up of equipment.

The processing load added by the supervision unveiled serious problems in the ECAs that were formerly occurring occasionally. Gradual buffer fill-up, communication freeze-up and several other bugs were detected and fixed.

The synoptics were developed on line. This permitted constant interactive check of the whole data acquisition chain, from the sensor to the screen displays, together with the validation of the Oracle database information.

Tuning

Besides facilitating daily operations, tuning revealed flaws in our systems. For instance PID parameters had not been adjusted by the firms because it required too much time.

On the other hand we had to exonerate networks, which were blamed for all problems. Inter-point communication was established only long after the LEP start-up. The heterogeneous architecture did not ease exploitation. Hence our system kept a bad reputation, but when all unrelated control problems were solved the accusations vanished.

The local supervision system acts now as a referee between dueling persons. Since process interactions cannot be misinterpreted, the debates are always constructive.

New investigation techniques

After a short learning phase the operation and maintenance team was capable of performing periodic checks of the main systems to prevent problems. Later, when the alarm system and its associated paging became operational, they could react even more promptly.

Recently we started using curve analysis to implement conditional maintenance. By observing evolution of the duty cycle's frequency, we were able to detect minor leaks in LCW circuits and refrigerant losses in the electrical alcoves' air conditioning units. Since both places are not accessible during LEP operation, we planned future interventions in agreement with the physicists. We then could fix the problems in a timely and cost effective way.

In the past, considering the limited investigation tools, the TCR would have called the people on duty indicating that a major leak had occurred in the tunnel. Driving distance between LEP pits, night-time intervention, customs procedure for spare parts transit, and … Murphy's law could lead to a long interruption of physics.

This new active approach is priceless and has reduced dramatically LEP failures due to HVAC systems.

CONCLUSIONS

In a timely way, with limited budget and resources, we designed the local supervision system that was missing for the LEP cooling and ventilation processes. The choice of LabVIEW allowed non-programmers to write most of the code and develop specific features to suit the needs of the operation team. The initial goal was rapidly exceeded, and this system now acquires 30,000 points of data, stores them at one minute intervals, and features synoptics, graphs, alarms and long term archiving.

This accomplishment allowed the full debugging and tuning of the controls of the LEP cooling and ventilation equipment. Moreover, by motivating the personnel and the operation team, this successful project triggered a change in mentalities and established a new style for system operation.

References:

[1] Interfacing industrial process control systems to LEP/LHC,M. Rabany , Icalepcs conference Tsukuba 91, Proceedings p269-273