INRIM TIME AND FREQUENCY LABORATORY: A NEW DATA MANAGEMENT SYSTEM (DMS)

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Abstract

INRIM Time and Frequency Laboratory relies on an automatic measuring and controlling system, whose functions is basically to collect, in a continuous way, essential timing measurements and synchronization data, together with information about the status of all the equipment involved in the measurement processes. The present system, that has been operational for over 10 years, will be replaced by a new version that is in a development phase, increasing system reliability and coping with ISO/IEC 17025 standard requirements. The so-called Data Management System (DMS) is expected to reach its Full Operational Capability (FOC) most likely during the first months of 2011.

INTRODUCTION

The INRIM Time and Frequency Laboratory, hereafter indicated as TFL, realizes and makes available to the users the UTC (IT) time scale, the legal time scale for Italy **[1]**. Generated by means of cesium-beam frequency standards, active hydrogen masers, and cesium atomic fountains, it is synchronized via satellite with those generated by other international NMI (National Metrological Institutes) and it is kept in agreement with the international time scale UTC (Universal Time Coordinated) computed by the BIPM (Bureau International des Poids et Mesures).

INRIM regularly contributes, with its atomic clocks and together with almost 70 international laboratories, to the realization of the UTC time scale, sending to BIPM the measurements results carried out following protocols defined at international level.

The INRIM TFL, at present, is equipped with a set of measuring and control devices (SAD – Sistema di Acquisizione Dati), characterized by the task to collect and to archive essential measures, to log the status of the main devices, and to exchange synchronization files with other international laboratories **[2,3]**. This system, that has been operational for over 10 years, in addition to the obsolescence of the items of equipment, has some limitations due to the technology evolution, implemented software, and new measurement needs.

TOWARDS A NEW DATA MANGEMENT SYSTEM (DMS)

In order to improve this situation, increasing the system reliability and coping with the ISO/IEC 17025 standard requirements, a new system has been designed in 2009. This system, called DMS (Data Management System), is based on a relational database to perform and store all the measurements automatically carried out by the local measuring systems. This database-oriented approach offers useful features, such as an implicitly efficient data structure in terms of tables, together with the possibility to effectively destructure complex data (such as text files in standard formats) down to simple and effective piece of information. As a consequence, the DMS will allow for an efficient integration of data coming from different and heterogeneous sources, aiming to provide a set of valuable products, both on demand and automatically scheduled. From the hardware and software implementation point of view, the DMS will be characterized by significant scalability and modularity, in order to achieve an efficient life cycle management, as well as to allow easier future expansions by adding new functions as they are needed. The DMS will be also provided with advanced features allowing us to monitor and control the system both locally and remotely, to automatically generate appropriate warning messages in case of anomalies, to easily retrieve and organize data, and, finally, to generate printed reports.

DMS DESIGN DRIVERS

In the definition of the most appropriate roadmap in relationship with the general aim, it has been considered essential to address the efforts on the overall management of the data that, on different basis, are related with the INRIM TFL (time and frequency measurements, environmental parameters, synchronization techniques products, etc.). In fact, the objective is to achieve a strong integration among all the different data and to achieve high added value products, not only for the laboratory operators' needs (reports, processing, diagnostics, etc.), but also for external institutional and commercial entities (BIPM, ESA, etc.).

From a functional point of view, it has been decided to extend the "data acquisition system" concept, adopted until now, to a more complex "data management system," able to acquire, process, archive, and put at the disposal of users all the products related with the INRIM TFL (time scale generation, dissemination, etc.).

In this frame, the DMS has a fundamental role, it being both an internal and external data collector and provider (server) of these data for general applications, like a more robust system for the generation of UTC (IT) time scale. In that sense, a common, widespread, and properly organized data archive is to be set up, overcoming the current physical information fragmentation that makes difficult any transversal analysis.

MAIN DMS FUNCTIONS AND HARDWARE REALIZATION

Among the different tasks foreseen for the DMS, could be envisaged:

- *acquisition and storage*, that is, the capacity to acquire time and frequency measurements, and environmental and control parameters, together with other products generated by other complex laboratory systems;

- *supervision and control*, that is, the function to supervise the general status of the system, with the capability to detect and warn about potential anomalies;

- *configuration*, that is, a wide range of capabilities in terms of programming and flexibility of the system functions.

In detail, the main DMS functions are:

- automatic and manual execution, by means of an electronic Time-Interval Counter (TIC), of time and frequency measurements between the UTC (IT) reference and cesium-beam frequency standards, hydrogen masers, and other laboratory equipments;

- phase measurements (started manually), performed by means of a multichannel phase-meter, among couples of frequency standards;

- acquisition and processing of internal parameters of atomic standards operated by the INRIM TFL, the temperature and humidity of each room composing the INRIM TFL and outside environmental parameters;

- automatic generation of the "data bulletins" to be sent to either the BIPM or other laboratories, with flexibility in the selection of the rate and of the generation schedule;

- daily generation of an internal report containing the most important DMS measurements to be consulted and automatically archived;

- acquisition and parsing of the files generated by the GPS (Global Positioning System) and the TWSTFT (Two-Way Satellite Time and Frequency Transfer) synchronization systems.

Concerning the realization, the following hardware devices have been taken into account:

- Commercial electronic Time-Interval Counter (Stanford SR620) for the time and frequency measurements;

- Multichannel coaxial multiplexer (RACAL 1256) for the cyclic commutation of the signals to be sent to the TIC, provided with 50 input channels and two output channels;

- Commercial high-resolution multichannel phase comparator (TimeTech 10265) for the phase measurements;

- Commercial data logger (LSI Lastem E-LOG) for the acquisition of the environmental parameters;

- Industrial PC (Windows XP OS) for the execution of the control and management routines;

- Standard interfaces like Ethernet, RS-232, USB for the communication of the different DMS devices.

All the listed devices are equipped with dual power supply systems and with spare units, in order to improve the system robustness and reliability.

In the following Figure 1, the DMS functional scheme and the current implementation of the different equipment are reported.

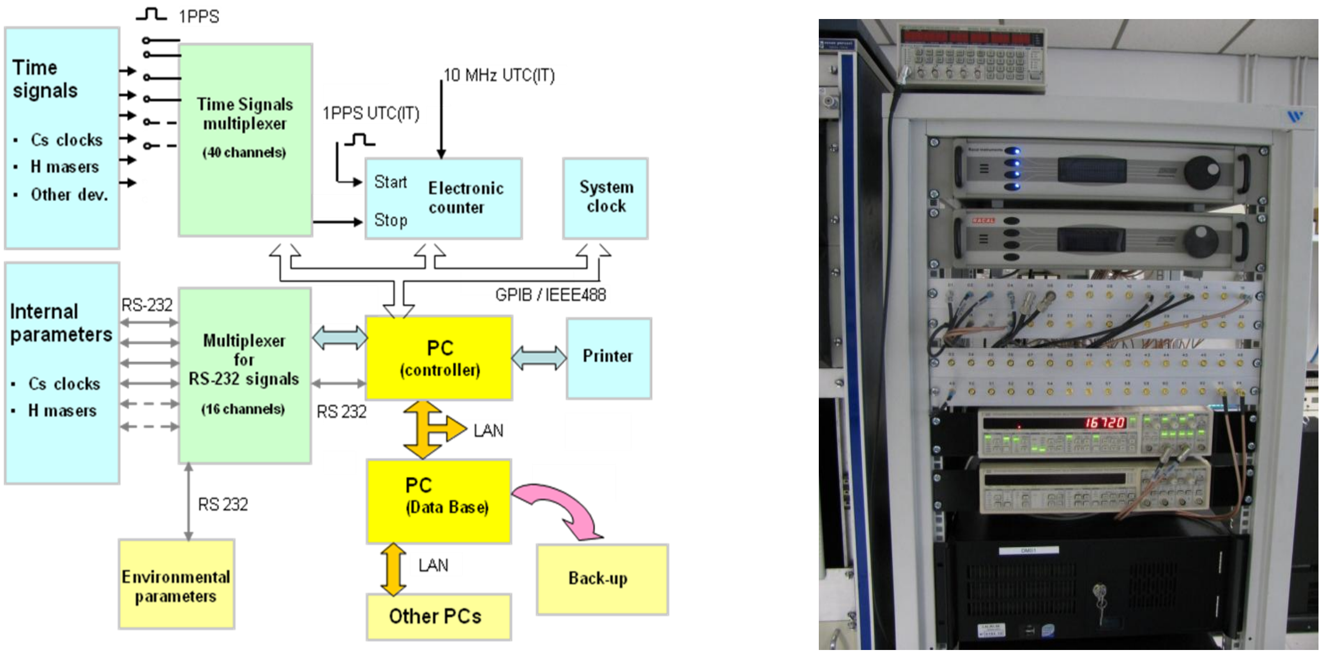

Figure 1. DMS functional scheme and HW realization.

SOFTWARE REALIZATION

Considering the DMS complexity and especially its expected life cycle (at least 10 years), the DMS software has been designed in order to be characterized by a large modularity, in order to allow future expansions, when new requirements will be necessary, and easy maintenance. Based on consolidated developing models, considered as the "state of the art" for the realization of a modern and professional software, the DMS has been designed following a component-interface approach. This approach allows a project to be split into several easy components that are independent from the system where they have to be implemented and with the task of satisfying only a reduced number of the overall requirements. All the different components are then linked together by means of "interfaces" that are independent by the physical means where they have to be implemented, and that have the task to drive the information and commands. Furthermore, this approach will allow for a "warm" replacement of the components and the configuration of the whole system. These characteristics are very important for a system that is committed to operate 24 hours per day.

In detail, the DMS software has been developed in "Object Pascal" to be run under Windows XP Operating Systems. The application software is linked to an open source relational database, mySQL, with the specific task to store all the interesting data. Using the Windows Registry tools, some specific mySQL tables, and other advanced solutions (like XML files), the DMS is totally configurable in "run-time," avoiding compilation of source code and also allowing for a significant interaction between the DMS and the operator. For the future, we also foresee the use of scripting techniques (like PHP), which are able to grant a wide range of DMS customization. Updating and integration of new functions are examples of capabilities that in the future could be carried out, without modifying the source-products code. In the following Figure 2, the current (prototypical) DMS SW management panel is depicted, where recently collected measures, measurement setup information, and devices monitor and control are synoptically reported.

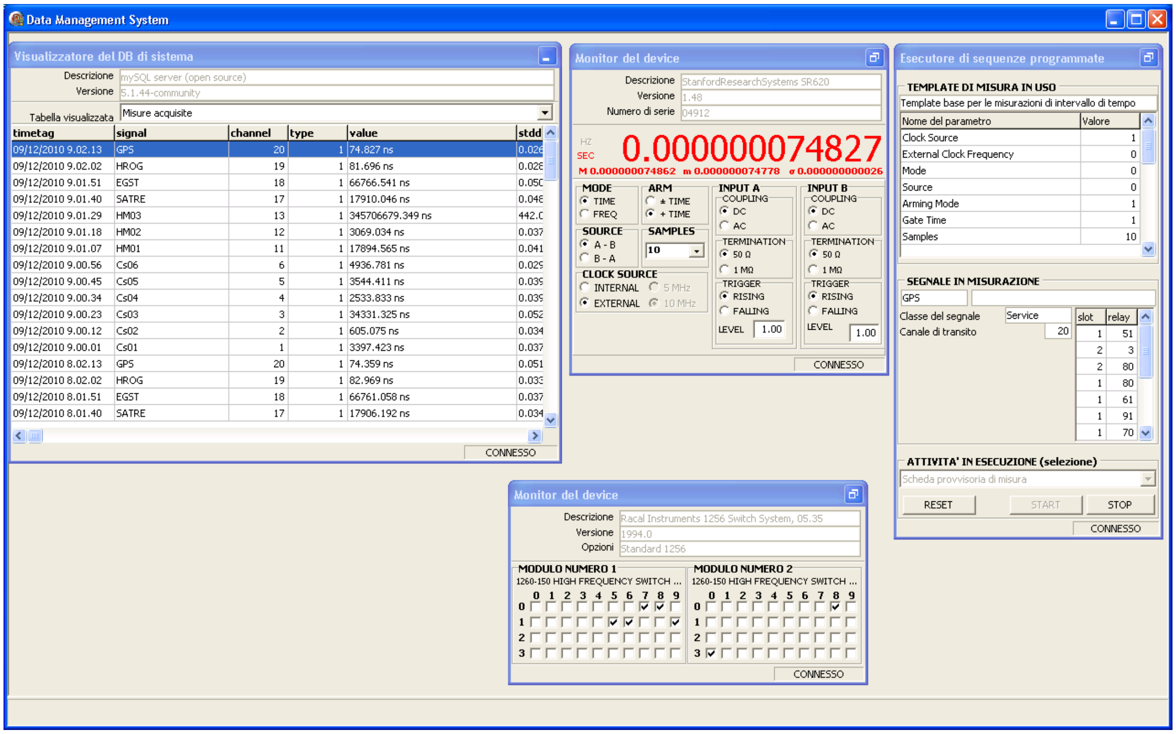

Figure 2. DMS SW management panel.

FIRST RESULTS OF A PRELIMINARY TEST CAMPAIGN

After about6 months of operation of an experimental version of the DMS, a detailed analysis of the results was carried out. At the beginning, the system was tested with manually operated measurements; afterwards, the DMS automatic scheduling with a rate of 1 hour was carefully checked. During these tests, it was possible to perform a complete debugging of the system and to have a functional check of the instruments, the software, and the database.

The experimental version of the DMS provides almost all the final equipment setup, it can guarantee a measurement rate similar to that of the actual SAD, it records the data in the database according to the final format, and allows one to access them through internal database tools.

The kind of measurements implemented in this phase is a subset of those that are planned for the final version. They concern time-interval measurements between the reference signal (1PPS) of the time scale UTC (IT), versus the similar signals of the six INRIM cesium-beam frequency standards (CS01, CS02, CS03, CS04, Cs05, and Cs06), of the three hydrogen masers (HM01, HM02, and HM03), of the TWSTFT modulator (SATRE), and of the reference time scale of the Galileo System receiver (EGST).

The data collected by the DMS were compared with those given by the SAD, in order to check the mutual compatibility. For the comparison, hourly data were considered, namely a mean value over ten consecutive readings, with a rate of 1 s, of UTC (IT) - SGN_{SAD}, and of UTC (IT) - SGN_{DMS}, where SGN identifies the generic measurement signal (CS01, CS02, ..., HM01, …), while the subscripts (SAD and DMS) indicate the measuring system used.

The data set used for the comparison covers a period of about 4 months (29 July to 6 December 2010, approximately 130 days), for a total of some 3100 data for each of the 11 measured signals. The DMS worked regularly throughout this period, with the exception of some events in which a fault in the TFL power supply system caused outages for some hours.

The time-interval measurements given by the two systems were mutually compared computing the residuals δ_i between the corresponding readings:

$$\delta_i = [UTC(IT) - SGN_{SAD}]_i - [UTC(IT) - SGN_{DMS}]_i - \Delta_i$$

The behavior of these residuals was corrected for the differential delays Δ_i (constant as a first approximation) of the different measurement channels. These corrections take into account the delays introduced by the equipment and by the cables connecting the signals to both the systems.

These residuals have, as expected, a mean value close to zero, while their fluctuations represent an estimation of the level of agreement between the two set of measurements.

Figure 3 reports, as an example for a cesium and for a hydrogen maser, the behavior of the σ residuals versus MJD. In the graph, for the sake of readability avoiding an overlapping of the curves, the ordinate values are shifted by a constant value, inessential for our evaluations.

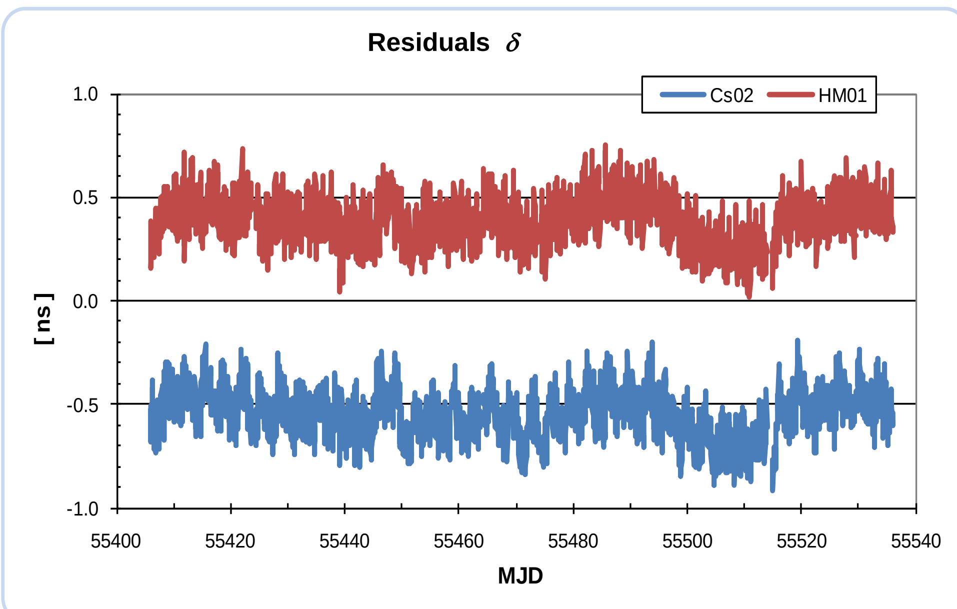

Figure 3. Residuals of Cs02 and HM01 signals.

Applying simple statistics on the residuals, the standard deviation σ_δ of the different compared signals is reported in the following.

Cs01	σ_δ = 0,12 ns	HM01	σ_δ = 0,11 ns
Cs02	σ_δ = 0,16 ns	HM02	σ_δ = 0,12 ns
Cs03	σ_δ = 0,12 ns	HM03	σ_δ = 0,11 ns
Cs04	σ_δ = 0,24 ns	SATRE	σ_δ = 0,16 ns
Cs05	σ_δ = 0,14 ns	EGST	σ_δ = 0,12 ns
Cs06	σ_δ = 0,20 ns		

Looking at these results, it can be inferred that the DMS worked as expected during the tests and the experimental results of the two measuring systems are in agreement, with residual fluctuations at level of hundreds of picoseconds. It is worth underlining that the fluctuations of the comparisons are caused by the resolutions of the time-interval counters (100 ps for the SAD, 25 ps for the DMS), together with the fact that the compared readings are not exactly synchronous. Indeed, for a different sequence of the two systems in scanning the channels, the time tags of the two compared signals can be different, reaching in some cases even 100 s.

CONCLUSIONS

According to the design specifications and the experimental confirmation of the expected results, it can be concluded that the DMS is a valuable tool to replace the SAD of the INRIM Time and Frequency Laboratory. Its final performance, designed to have greater flexibility of operation, and better security and adaptability to new metrology needs, is estimated to fully meet the current and future needs of the laboratory.

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