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Product-Based Industrial Information Systems (Application to the Steel Industry)

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***Abstract*—**This paper shows a simple and effective approach to the design and implementation of Industrial Information Systems (IIS) oriented to control the characteristics of each individual product manufactured in a production line and also their manufacturing conditions. The particular products considered in this work are large steel strips that are coiled just after their manufacturing. However, the approach is directly applicable to coiled strips in other industries, like paper, textile, aluminum, etc. These IIS provide very detailed information of each manufactured product, which complement the general information managed by the ERP system of the production line. In spite of the high importance of this type of IIS to guarantee and improve the quality of the products manufactured in many industries, there are very few works about them in the technical literature. For this reason, this paper represents an important contribution to the development of this type of IIS, providing guidelines for their design, implementation and exploitation.

***Keywords*—**Data storage, industrial information systems, measurement systems integration, signal acquisition.

I. Introduction

THE measurement and storage of the characteristics of very-long flat products and their manufacturing conditions is a complex task. As an example of very long flat products, the reader could think in all those products that are coiled just after their manufacturing, like steel strips, aluminum film, very long paper sheets, textile strips, etc.

This paper deals with the design of a system capable to integrate the great volume of information generated by many different measurement systems during the manufacturing of each product. Each system generates the information with different formats, acquisition rates, etc. Therefore a proper integration is essential in order to the whole information can be easily exploited by plant engineers to develop several tasks: quality control of the manufactured products, maintenance of the manufacturing facilities, production planning, etc.

The system presented in this paper has been designed for a rolling mill, in which, hot steel blocks are rolled until they became long strips that are cooled with water to give them mechanical properties, like tensile strength, yield stress or hardness. Finally, the long strips are coiled and stored.

Although this industrial information system has been specifically designed for the steel industry, the concepts applied in its design are applicable to many other systems.

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II. Description of the Industrial Line and its Measurement Systems

The information system presented in this paper collects all the information relevant for the thermal treatment applied to the steel strips during the final phase of their manufacturing. Fig. 1 shows a lateral view of the Hot Strip Mill installed in Aviles, Spain, by the steel manufacturer ArcelorMittal. In this figure, the hot strip moves from left to right. Initially, a very thick plate arrives to the first rolling stand of the Finishing Mill, named F0 in the figure. After passing between the rolls of the other six stands, F1 to F6 in the figure, the hot strip leaves the finishing mill, and its basic dimensional properties, like the thickness profile or the width, should be near of the objectives established for its manufacturing.

Then, the strip goes into the cooling table. While the strip moves forward on this table, it is cooled by until 12 water curtains. There are 12 curtains over the strip and also other 12 correspondent curtains under the strip. The bottom showers project a water curtain against the lower side of the strip, receiving the entire strip approximately the same quantity of water coolant. But the water projected by the top showers must be eliminated falling by the two edges of the strips, provoking an overcooling of the edges.

To avoid this effect, an edge-cooling masking system is installed in the showers 4 to 8. This system picks the water of the upper curtains that falls on the edges of the strip. By this way, the strip edges are cooled only by the water projected in the central part of the strip that is evacuated falling by both edges of the strip.

Finally, the strip is coiled and sent to a cooling park because the strips are coiled with an average temperature of 400ºC approximately.

Days or inclusive weeks later, the strips with unacceptable quality are sent to the improving line. In this line, the defective sections of a strip are eliminated, obtaining two or more shorter strips from the original one.

There are multiple measurement systems installed in this hot strip mill. Next paragraphs explain the most relevant aspects of these systems.

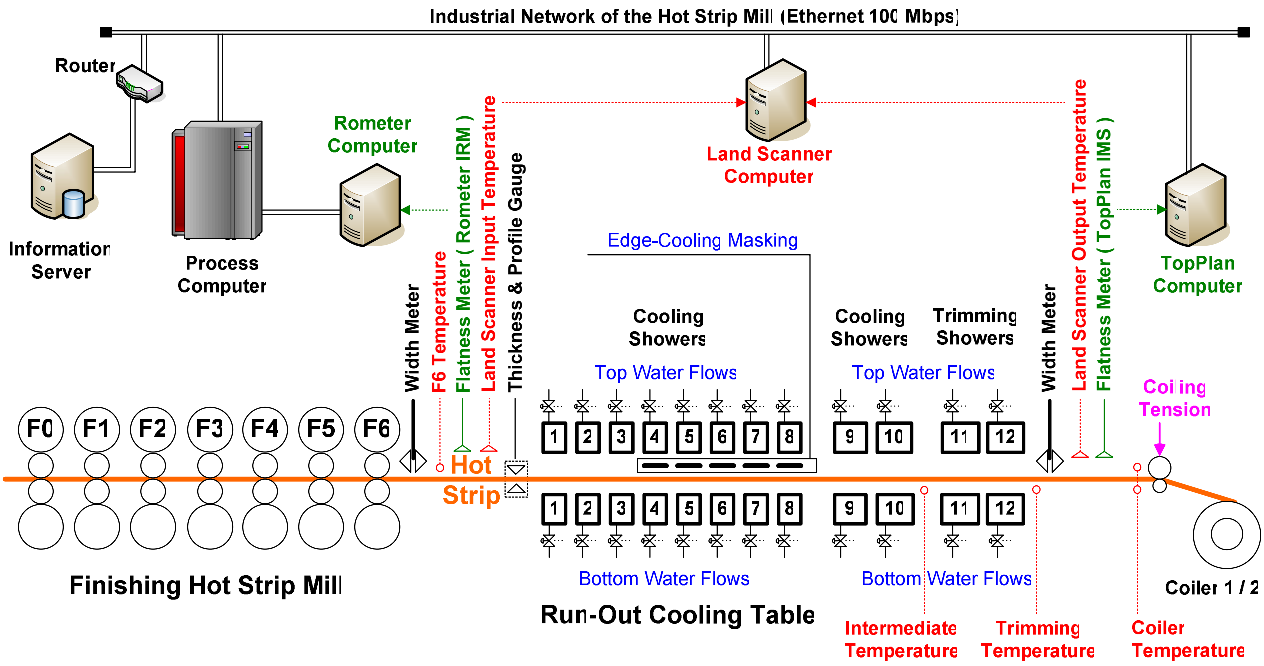

Fig. 1 Schematic diagram of a Hot Strip Mill with its main sensors and computer systems

The most complex measurement systems are devoted to the measurement of the flatness of the hot strips. The Rometer system measures the strip flatness at the input of the run-out cooling table and the TopPlan system does it at the exit. Each system is controlled by its own dedicated computer that provides a kind of two-dimensional flatness map just after the processing of each strip. The maps are composed by a sequence of scans and each scan contains several measurements of the strip flatness. Fig. 2 shows how the flatness measurements are taken from the strips.

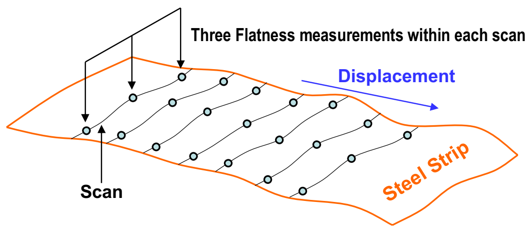

Fig. 2 Measurements of flatness integrated in scans

The Rometer system always provides five measurements in each scan independently of the width of each particular strip: one taken in the center, two in the edges of the strip and other two just between the center and the borders. The TopPlan system always uses scans of 2 meters taking 60 measurements within them. Therefore, the number of flatness measurements taken for each particular strip depends on the width of the strip. Both systems represent the flatness in I-Units, but Rometer uses a scale in which the I-Units can be positive and negative while TopPlan only provide positive I-Units. In these systems, the distance between successive scans may be different because the speed of the displacement of the strip along the mill is variable.

We need a unified manner to store and visualize this type of 1D-signals (or 2D-maps) that can be measured with very diverse formats in different mills or even in the same mill.

Other important measurement systems are the thermographic scanners, one placed at the input of the run-out cooling table and the other placed at the output. Both scanners are controlled by the same computer which provides a pair of two-dimensional temperature maps of the strip. Each map is composed of a sequence of scans, and each scan contains 1000 temperature measurements. These sequences of temperature scans are just another type of 1D-signals (or 2D-maps) that must be stored and visualized in the same manner than the flatness information.

There are also other measurement systems that provide a single signal, like the two strip width meters, based on image processing technology, and the strip thickness and profile gauge, based on x-ray technology. In spite of the high internal complexity of these measurement systems, they only provide a single signal during the processing of a hot strip, which is sent to the process computer of the hot strip mill.

Finally, there are sensors devoted to measure temperatures, water flows, coiling tensions, etc. All these sensors are connected to the process computer by a sensor network.

The great diversity of the signals to be stored and later analyzed and visualized for each manufactured strip requires a specific approach to the development of an industrial information system focused in the manufactured products, in this case hot steel strips.

III. Related Work

Before starting the design of a new specific industrial information system (IIS), an analysis of the currently available techniques and systems has been developed.

Generally, the research works on the design and deployment of industrial information systems (IIS) may be classified in two types considering the volume of the information managed.

The first type comprises the works that consider all the information used by an industrial enterprise during its normal operation, and including: product design, raw materials acquisition and handling, manufacturing process, product selling and delivery, financial and accounting, human resources management, etc. All this information is integrated and processed by an Enterprise Resource Planning (ERP) System that is a complex software system composed by many modules closely integrated between them. A particular successful implementation of an ERP system [1] is provided by SAP, the largest European software company. Berchet and Habchi [2] documented the implementation and deployment of an ERP system in a large industrial company and Loarne [3] analyzed the results of the implementation of an ERP system in a multinational firm specialized in the transformation of raw materials. Besides ERP, there are many other systems and approaches for the information integration in industrial enterprises. Cioca [4] provides a good classification and analysis of these systems.

The second type comprises the works that consider partial information systems of an industrial enterprise. In this work we have focused the attention in those IIS whose objective is to track the characteristics of the manufactured products as well as their manufacturing conditions.

The design of an industrial information system oriented to track and manage the information of each product manufactured in an industrial installation involve many aspects, like signal and data gathering, design and implementation of databases, information visualization including access from web, networking issues, etc. Therefore, the bibliography is also very diverse and often focused in one of these aspects. However, a general overview of the available technologies to implement many of these aspects can be obtained from the book of Boucher and Yalcin [5].

The interest of the industry in the development of IIS is not recent. Guetari and Piard [6] conceived a method to support the development of object-oriented systems for operation management in industrial companies. Other example of the utilization of object-oriented technologies was provided by Fernandes and Machado [7] that applied these technologies to the development of the industrial control-based information system of a textile factory.

Many other technologies have been progressively introduced in the development of industrial information systems. Arch-int and Batanov [8] used web technologies, and Framling et al. [9] proposed the utilization of agents.

Other research works focus their attention in the communication issues. Verissimo et al. [10] developed the NavCim architecture to manage all the information flows in an industrial factory. Lunheim and Skavhaug [11] proposed an experimental setup for the evaluation of networking technologies to achieve better horizontal and vertical integration of industrial information systems.

The conclusion of the analysis of the related work is that there is a rich literature about the design and deployment of very large IIS, like the ERP systems, and there also are several general studies about the technologies used to implement IIS. However, there is a total lack of works about the design of specific IIS oriented to track the characteristics of each individual manufactured product and its manufacturing conditions, which are defined by the values of the processing variables, like pressure, temperature, etc.

IV. The Proposed Solution

The proposed solution is based on the integration of small programs in all measurement systems and process computers which collect the information required to send it to our information system. We also have designed a flexible format to accommodate the great diversity of formats of the original measurements.

Each strip has a unique product code assigned by the central computer of the factory. This strip code is sent to all process computers and measurement systems of the factory that send information to our industrial information system.

After the manufacturing of a strip finishes, the measurement systems send a file containing the information collected to our information system. The name of the file contains the date/hour, the strip code, and the identification of the measurement system included in the name of the file.

Due to the work developed in each process computer and measurement system, they may send the file of a strip just after finishing its manufacturing, or until several hours later, for example due to an operational failure of a communication network. Therefore the collection of information of each strip is an asynchronous process.

Anyway, when the information system receives a new file with measured strip data, it checks if there is already another file of that strip in the system. It there is a file, the information of the new file is integrated in the existing file. The information system always maintains all the information of each manufactured strip in a single file.

All the communications are developed using the client server paradigm. The industrial information system is installed in an information server, and the measurement systems and the process computers play the role of clients that establish a connection with that server to upload files using the standard File Transfer Protocol (FTP).

V. Design and Implementation Aspects

In this section three basic aspects of the design and implementation of the IIS will be analyzed: the process of information integration and storage; the internal format of the files containing the information of the strips; and the integration of functions oriented to improve the operational reliability of the IIS.

A. Information Integration and Storage

The IIS receives information in an asynchronous manner. The clients send files when they have just finished the processing of the measurements obtained from a strip. The FTP service installed in the information server receives the files and store them into the FTP incoming directory. The information integration & storage service processes these files and generates only one file for each strip that is stored in the IIS directory tree. Fig. 3 illustrate this processing.

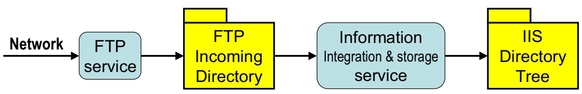

Fig. 3 Processing of the files received by the IIS

The integration & storage service looks for new files in the FTP incoming directory each 30 seconds. When it finds a new file extracts the strip code and the manufacturing date-time from the file name and uses both to find the correspondent strip file in the IIS directory tree. If the strip file exits, the service integrates the information contained in the new received file into the strip file. In the contrary case, the service creates the strip file using the information of the new received file.

All the strip files are generated in a compressed format using a ZIP compressor. This compression library was selected between ZIP, RAR and ACE because it offered the best tradeoff between the compression rate and the required compression time.

The final storage of the strip files is done in the IIS directory tree. Fig. 4 shows the extreme simplicity of the directory tree: year → month → day. With this scheme the strip files are stored indexed by the manufacturing date automatically.

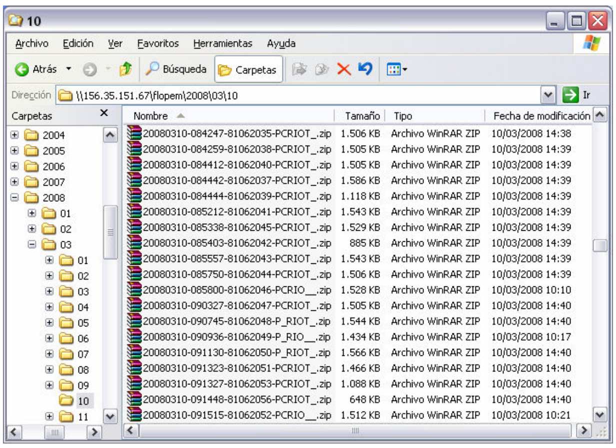

Fig. 4 Scheme of the IIS directory tree

Within the directory of any day of a year the strips are also automatically ordered by their manufacturing date because the name of each file starts with the date and the time in which the strip was manufactured.

This IIS does not include any database to support complex searching of a particular strip. The hot strip mill has its small ERP and strip tracking information systems that could be used by the operators to find the manufacturing date of any particular strip. Using the manufacturing date, the localization of the strip file in the IIS is straightforward.

B. Internal Format of the Stored Files

In order to store the information of each strip several designs can be considered for the internal structure of the files. The design should be enough flexible to accommodate the large variety of signals and information that must be stored for each of the manufactured strips.

Today, there is a strong tendency to store the information in plain text labeled with XML tags. This approach is impracticable in this kind of information systems due to the very high volume of information handled (stored) for multiple signals in each strip. Therefore the signals of each strip must be stored in binary format, in order to save as disk space as possible.

An appropriate organization of this file is also required to accommodate multiple signals of different types. Fig. 5 shows an appropriate design for the organization of this file. The file is structured in several sections: a header section followed by 1 to N sections to store signals and finishing with an extra data section. Now, these sections are briefly explained.

The header contains the information required to manage different types and versions of the file format. It is composed of seven fields. The *signature* identifies the type of the file and the *file version* allows the specification of small variations into the format of the file type. The *creator program* allows the identification of the data-login system that created the file. This is convenient because this format has been designed in order to diverse data-login systems store information using it and this field allows its identification. Next, the *compression* field allows the identification of the compressor used to compress the signals, and the *number signals* field indicates the number of the following sections within the file, containing each section one signal.

All the sections of the file devoted to store a signal have the same structure. These sections begin with ten fields that describe the signal stored within the section. The last field, called *data*, contains the measured values of the signal. Due to this section includes the size, the dimensions data (values of the axes in each of the dimensions) and the maximum and minimum values of the signal, the file with the signals can only be generated after all the signals have been acquired and preprocessed completely.

Finally, the extra data section is used to store information that is not acquired continuously during the manufacturing of a strip, like the signals. Generally, the extra data section is used to store single values of the strip, like its weight, length, or the code of the cooling strategy used in its manufacturing.

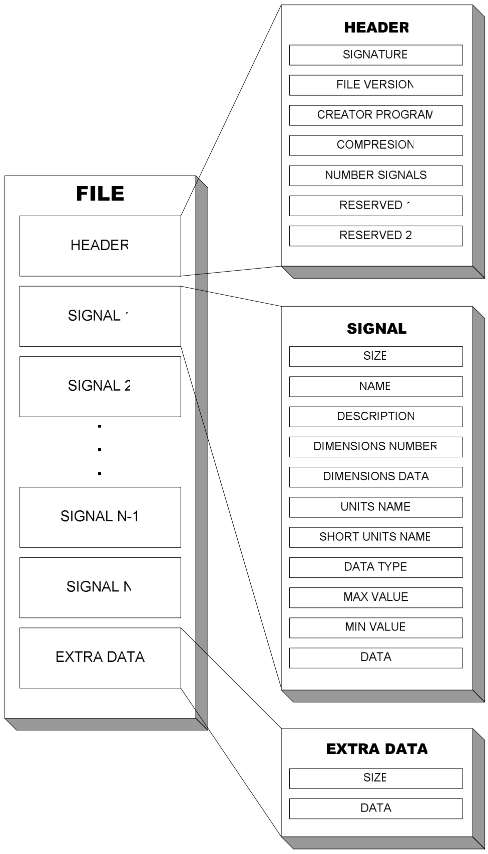

Fig. 5 Internal Structure of the files

C. *Improvement of the Operational Reliability*

To increase the operational reliability of an IIS some functions may be included in it. An important function must be devoted to guarantee the availability of disk space to store the information contained in the new files received by the IIS. To achieve this, a service checks the occupation of the disk just after the processing of each new file. When the disk occupation surpasses the 80%, the service sends an e-mail to the manager of the IIS. But, when the disk occupation reaches the 90%, the service eliminates files starting from the oldest one until the disk occupation reaches the 70%.

Other important function is devoted to check that the clients send the information to the IIS within a reasonable period of time. To implement this function, a service starts every day at 1:00h to analyze the files of the directory correspondent to the previous day. Analyzing the last six characters of the file name, this service can detect the clients than have not sent the information. As an example, a file name finishing with "-PCRIOT_." indicates that all the six clients have sent their information and has been stored in the strip file. A file finishing with "-_____T_." indicates that only the TopPlan flatness measurement system has sent the information to the IIS. The service calculates for each client the percentage of files that does not contain information of the client. When the percentage surpasses the 5%, an e-mail is sent to the manager of the IIS.

Finally, all services record in a log file relevant operational events, like the start/stop of the service, the address/subject of the e-mails sent, the received coils with bad identification code and the controlled exceptions generated by the system.

VI. Exploitation of the Information System with a Visualization and Analysis Tool

The information stored in this IIS can be exploited in many ways. The information available of each strip is very detailed, and in general, it can be exploited by quality, production, and maintenance engineers.

As an example, when a quality engineer receives a customer complaint about one or several defects in any part of a strip (like, lack of flatness along the strip between meter 500 and meter 800), using the IIS, the engineer can find the file of the strip and analyze the exact situation and the magnitude of the defects.

Furthermore, the engineer can also analyze the production control variables, like the forces applied to the strip, the cooling rate, the strip speed during its manufacturing, etc., in order to detect changes that could explain the bad quality of that specific part of the manufactured strip.

This analysis provides an invaluable experience in order to the production engineers can establish proper settings for the production control variables of the different types of strips.

Of course, when the production machinery can not maintain the values of the production control variables at the defined settings, the IIS provides useful information to maintenance engineers indicating the need of maintenance in specific components of the production machinery.

A tool has been designed to visualize all the information of a strip contained in a file. Fig. 6 shows the interface of this tool, in top of which the 2D flatness map provided by the TopPlan measurement system is being displayed. This map shows severe flatness defects (wavy edges) between the meters 500 and 550 approximately.

Below this map, a 2D temperature map provided by the LandScan measurement system has been also displayed showing an unexpected transitory reduction of the temperature of the strip. A temperature signal has been displayed at the bottom of the interface to check the magnitude of the temperature valley along the center of the strip and an emergent window has been also opened to display the profile of the transversal temperature in the meter 539.

The utilization of the IIS described until now is done analyzing strip by strip with a high level of detail. Another possibility is based on the extraction of general information from many strips (like an average flatness index of the strip head) and the representation the information (index) for several consecutive days or weeks of production. This allows the detection of drifts in the quality of the manufactured products. Currently, these analyses are implemented as independent programs that generate Excel spreadsheets.

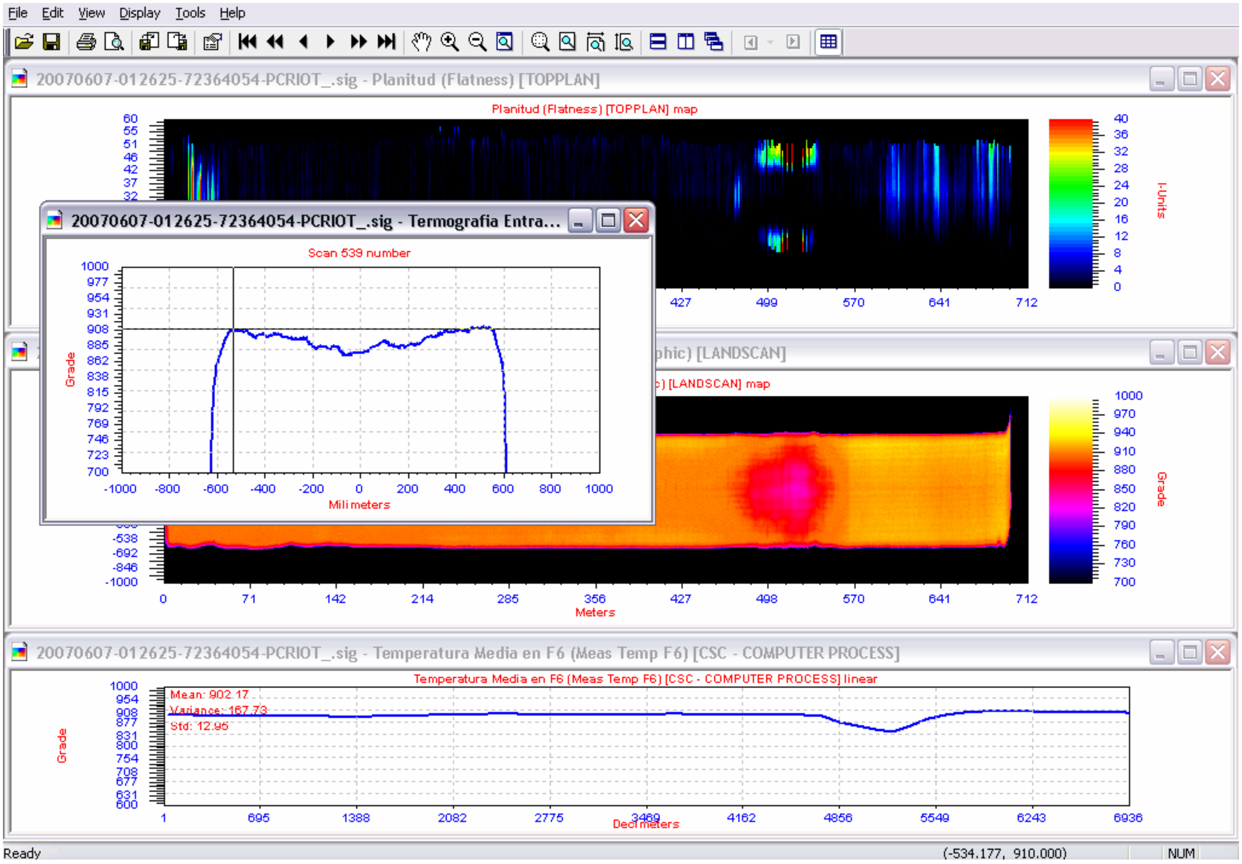

Fig. 6 General view of the capabilities of the visualization tool used to exploit the IIS

VII. Conclusion

This paper has shown the design and implementation issues of product-based IIS. These systems are oriented to support the storage and analysis of the characteristics of each individual product manufactured in a production line.

In particular, this work has been focused in very long flat products that are coiled just after their manufacturing and which are common in many industries, like steel, aluminum, plastic, paper and textile.

Product-oriented IIS provide very detailed (fine grain) information of each manufactured product, and they complement the general ERP systems already operating in the production lines, which provide general (coarse grain) information of the manufactured products.

The experience of the authors is that product-based IIS are invaluable tools for all the engineers involved in the operation of a production line.

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