The CFHT MegaCam control system: new solutions based on PLCs, WorldFIP fieldbus and Java softwares

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ABSTRACT

MegaCam is a wide-field imaging camera built for the prime focus of the 3.6m Canada-France-Hawaii Telescope.
This large detector has required new approaches from the hardware up to the instrument control system software. Safe control of the three sub-systems of the instrument (cryogenics, filters and shutter), measurement of the exposure time with an accuracy of 0.1%, identification of the filters and management of the internal calibration source are the major challenges that are taken up by the control system.
Another challenge is to insure all these functionnalities with the minimum space available on the telescope structure for the electrical hardware and a minimum number of cables to keep the highest reliability. All these requirements have been met with a control system which different elements are linked by a WorldFip fieldbus on optical fiber.
The diagnosis and remote user support will be insured with an Engineering Control System station based on software developed on Internet JAVA technologies (applets, servlets) and connected on the fieldbus.

Keywords : CCD mosaic, Shutter, Filter, PLC, Fieldbus, WorldFip, Grafcet, SCADA, JAVA, applets, servlets.

1 INTRODUCTION

MegaCam is a wide-field imaging camera built for the prime focus of the 3.6m Canada-France-Hawaii Telescope. This camera is based on a mosaic of 40 CCD. These ones provide with these customs CCD controllers are cooled down by closed cycle cryocooler founded on pulse tube. With his cryogenic part the instrument is equipped with a shutter and a filter sub-system (See Aune and al. [1] For more details). The shutter is composed of a 1m diameter half disk with an Internal Calibration Light Source (ICLS) put on it. The filter sub-system is created with a juke box containing eight filters, and a loading arm allowing to take away a filter under the mosaic. This instrument with all sub-systems is also provided with his own control system. This one is shared like the same three independent sub-systems :

- Cryogenic sub-system which includes all the components necessary for the CCD operation at the cryogenic temperature,
- Shutter sub-system which includes, of course, the control from the shutter but also the control from auxiliary functionnalities like exposure time management and the ICLS,
- Filter sub-system which includes all the components to choose a filter into the juke box and put it under the beam.

This sharing means that each sub-system may operate without the others. This design is kept on all the control channel and control cards. The main component in the control system is based on a Programmable Logic Controller (PLC) connected through a WorldFip fieldbus to a Supervisory Control and Data Acquisition (SCADA) named for this instrument Engineering Control System (ECS).
The ECS provides displays all the trends for all the sub-system data through Internet Explorer (5.0 and more). It also gives access to the observer and engineer commands. Analysis tools are provided to maintain and understand the

instrument operation. All these functionalities are available through a remote connection on the same Internet interface with any computer running Internet Explorer.
Observer commands are sent to the Control Unit (CU) through a VME board which makes the interface between the CFHT user interface and the WorldFip fieldbus.

2 CONTROL COMMAND ARCHITECTURE

2.1 Architecture overview

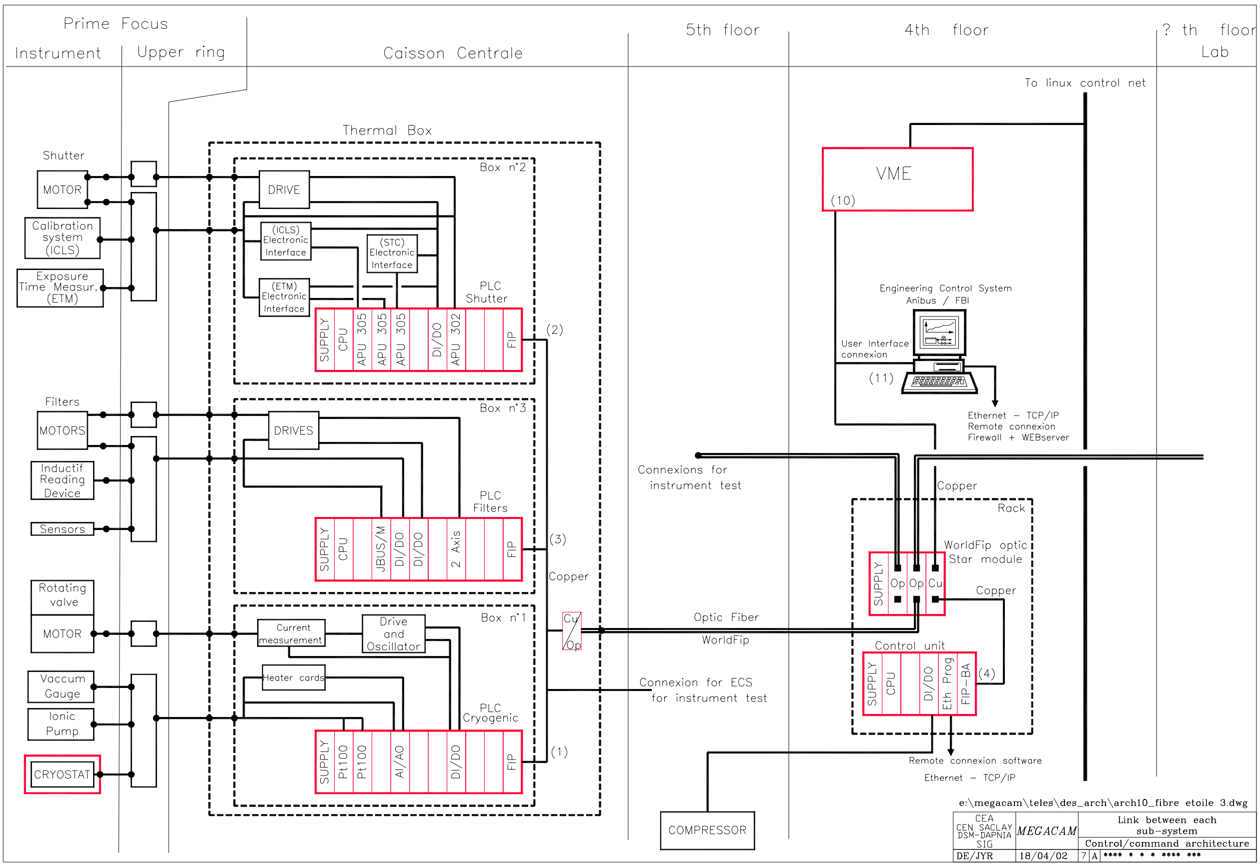

Figure 1 : MegaCam control command architecture

The control command architecture for the MegaCam instrument is based on PLC technology for his good resistance to the industrial environment. The figure 1 details this architecture. The PLCs are shared between two main parts:

- Remote PLC modules (RPLC) for the interface with each sub-system.
- Control Unit (CU) which contains all the control software.

The RPLCs are integrated on electrical boxes (shown in figure 4) which are installed in a thermal enclosure (CUTE) on the "caisson central". Each RPLC is connected to the CU through the WorldFIP fieldbus. The CU contains the instrument software and the fieldbus management ("bus arbitrator").
The main advantages from this sharing and its installation are:

- Have an independent sub-system,
- Minimize the connections between the telescope and the control room where the CU and the ECS are installed,
- Have a single access to the CU via Ethernet remote connection to maintain the control software from CFHT headquarter,
- Insure a good robustness and safety from the instrument,

- Put some fast software in the RPLC if the cycle time in the CU was too long during the project development.

For the filter and the shutter sub-system, the boxes contain a PLC axis card wired with drive to ensure good motion accuracy. The speed profiles are specially adapted to avoid shock on the mechanical structure.

2.2 WorldFip fieldbus

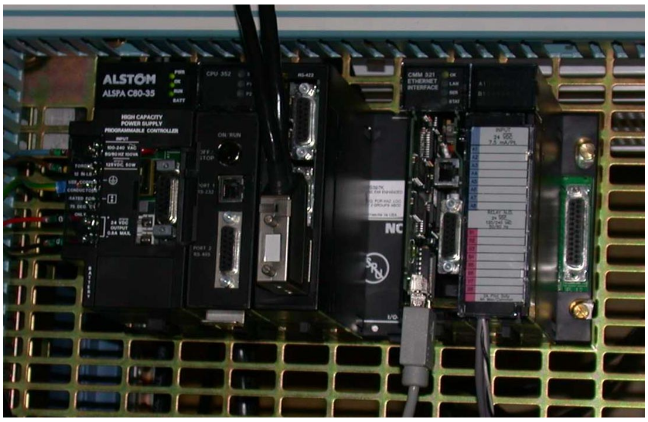

Figure 2 : Control unit PLC

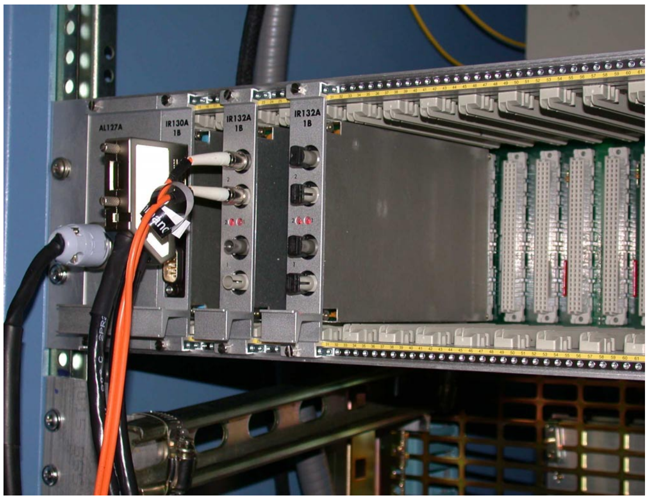

Figure 3 : Star module

The WorldFip fieldbus has been chosen for his deterministic exchange, his length capabilities and his electrical robustness in industrial environment. It has also the capability to adapt new development using acyclically message traffic. It is in conformity with the IEC 61508 norm (functional safety of electrical, electronic, programmable electronic safety-related systems). It is a preponderant element in the safety qualification for a control/command architecture and is recognized at the SIL3 level.

The WorldFip fieldbus operates using a producers-users model. This model allows all the users to consume a same datum with the same value at the same time. This main characteristic has been used for all the instrument statuses which are provided by the CU and consumed by ECS and CFHT user interface through the VME board.

In a WorldFip fieldbus, the CU is also the bus arbitrator (the fieldbus communication manager) for the network. This station must guarantee deterministic exchanges which are defined in a table built in the bus arbitrator. All exchanges between the RPLC, the control and the interface users are configured in 50ms. This time is compatible with the CU cycle time.

Special WorldFip data have been developed to simplify the communication. This development is used to send commands from the ECS to the CU. Its is based on encapsulation from a Modbus protocol on a WorldFIP data. This functionality allows to have one periodic datum to send any command at any time and add as many commands as needed during the project development without modifying the WorldFip data exchange.

As shown in figure 1, the different parts of the control system are connected on WorldFip through an optical link. This link eliminates all electrical noises and ground potential problems. This solution responds also to a MegaCam constraint which is to move the RPLCs at several points from the telescope building. This displacement may be total (the three RPLCs boxes are moved) or partial (one is moved). The optical support supposes that the topology moves to bus to a star topology. It is composed of:

- A star module which makes the connection between the copper and optical fieldbus and dispatch the information on each star branch,
- A repeater which converts optical fieldbus to copper.

2.3 Electrical integration

All sensors and actuators are connected to the RPLCs through connection boxes (shown in figure 5) installed on the upper ring structure. This design allows to:

- Minimize the cable numbers running on the telescope structure,

- Disconnect the upper ring easily.

To avoid any electrical noise, only two cables per electrical box (one cable for the measurement signal and another one for the power signal) are necessary to control one sub-system. The measurement cables are wired with a 32 pairs flexible ("snake") cable and a 61 points MS connector serial 851.

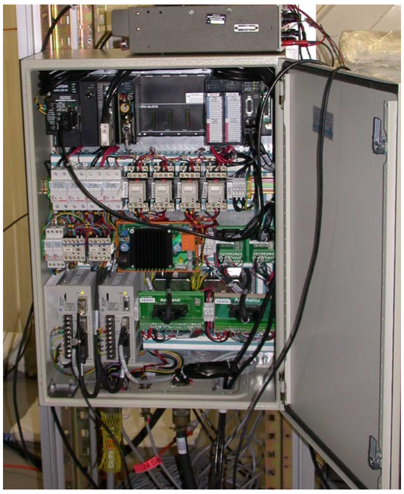

Figure 4 : the filter RPLC integrated in its box

Figure 5 : Connection boxes on the upper ring

2.4 Control Command software

The control command software is described with a GRAFCET. This specification language is normalized in the IEC 60848 ed. 2.0 since February 2002. It is used to describe the process in the project design phase and is translated in a Sequential Functional Chart (SFC) PLC code in the CU. Special displays have been created on the ECS and give debugging tools directly on the user interface.

The control command software creates faults which stop the affected process. These faults are also caught by the ECS.

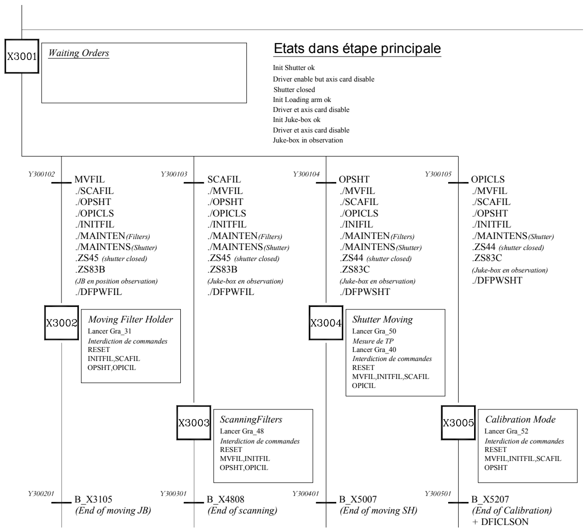

Figure 6 : Working document

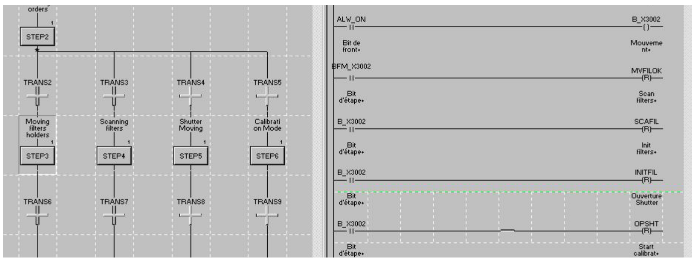

Figure 7 : PLC implementation

Figure 6 shows a GRAFCET working document drew on AutoCAD. Figure 7 shows the same GRAFCET implementation in the PLC.

3 SPECIFIC FUNCTIONALITIES FOR EACH SUB-SYSTEM

3.1 Cryogenic sub-system

Custom input cards with Pt100 temperature ranges were created by Horner on our request. These cards have an accuracy of 0.1°C in the range –200/+200°C. This characteristic is needed since the temperature regulation range is +/- 0.5°C. With these cards the temperature sensors are directly wired on the cryogenic RPLC. This design ensures a minimum space occupation in the cryogenic box for these measurement channels. For the temperature regulation three sensors are glued on the CCD cold plate. The CU computes an average from these sensors and gives a single temperature input to its PID block. This PID, programmed in the CU, pilots with one analog output several heaters glued on the CCD cold plate. These heaters have been mounted on the cold plate based on a thermal simulation. (See Aune and al.[2] For more details)

This sub system, like the other, had a special cabling which allows the detection of a bad connection during or before the instrument operation. On the cryogenic part, the pulse tube equipped with a rotating valve moved by a stepper motor is connected to the RPLC. A custom electronic card checks the connection between this stepper motor and its power electronics cards. It detects the currents in the motor phases and gives a digital input to the RPLC.

3.2 Shutter sub-system

The shutter provides a uniform illumination of the detector array with a minimum exposure time of 1 second. It should be done with a great uniformity of illumination, including the opening and closing period with a good knowledge of the effective exposure time. In addition to this inescapable requirement, the shutter is equipped with an Internal Calibration Light Source (ICLS) which allows to check the whole CCD readout chain. All these aspects are essential to preserve the capabilities of a good photometric analysis of the images during the lifetime of the camera.

3.2.1 Shutter time management

The shutter requirements for the exposure management were:

- Uniformity of exposure on each pixel: 1 %
- Minimum exposure time: 1s
- Accuracy on the exposure time measurement: 0.1 %

These requirements are reached and controlled by two blocks detailed in figure 8 : exposure time measurement and shutter time control. Exposure time measurement is realized with an optical sensor placed in front of the location of the first pixel of the CCD mosaic illuminated by the shutter rotation. A special PLC card measures the time duration of the signal generated by this sensor. The shutter time control converts the exposure time set by observers to a shutter time stop. At the end of the shutter opening, the stop time is taken into account by a PLC card to pilot the shutter closing.

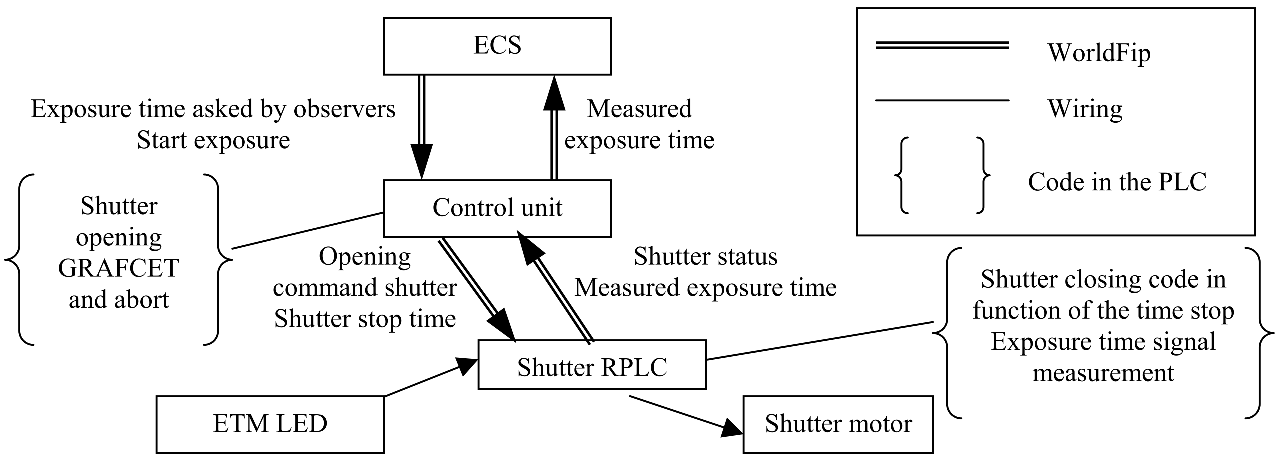

Figure 8 : Shutter time management

3.2.1.1 Shutter exposure time measurement

The Figure 9 shows the design of the exposure time measurement. It is based on the duration measurement from a signal delivered by an optical sensor put in the way of the shutter motion. This optical "fork" is formed by a LED source and a photodiode placed face to face. The "fork" is implanted on the guiding system of the shutter at an angular position where the shutter is at a constant angular speed. The rotation motion of the shutter gives a change of state on the optical receiver, thus allowing to measure with a great accuracy the real exposure time.
The photodiode signal is analyzed by an electronic device which sends out a signal with a width exactly equal to the time of illumination of the CCD mosaic. This signal is sampled by a PLC timer counter card, thus insuring the measurement precision better than 0.1%, i.e. 1ms for an exposure time of 1 second.
The optical source (SLED) and the photodiode (PhD) have been chosen to run at the optical wavelength of 1550 nm. The SLED emits a very thin light beam of about 30 microWatts which is completely included in the PhD area.
All these specifications allow to have no detectable stray light on the CCD mosaic during the exposure time. A test made on the MegaCam CCD testbench (see P. Borgeaud et all.[3] For more details), in much worse conditions, gave a satisfying result: with the optical "fork" directly placed in front of the CCD, the amount of stray light is equal to 1 ADU/hour/pixel, which is about 3 order of magnitude less than the estimated minimal sky optical background (U band) during the same time.

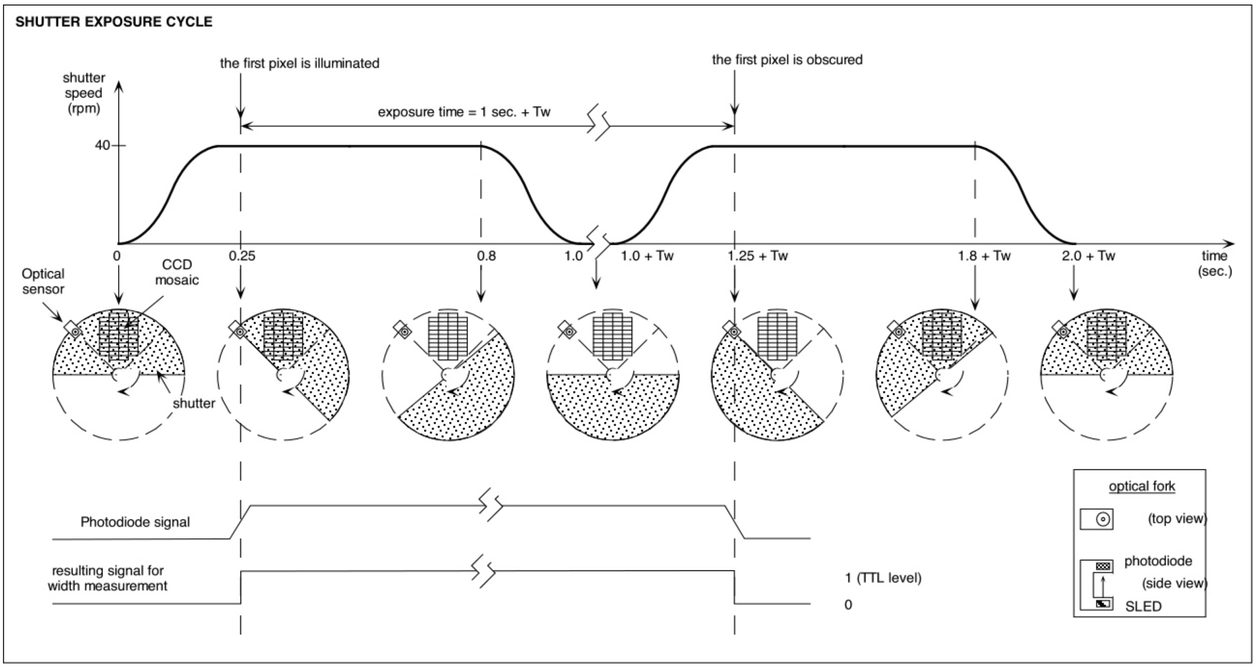

Figure 9 : shutter exposure time cycle


Figure 10 : View from the ETM optical sensor

The TTL output of the optical "fork" electronic device is sent to a High Speed Counter (HSC) module located on the shutter RPLC. This HSC input signal is sampled at a frequency of 10 kHz. The measurement precision reached with the complete chain is +/- 0.06%.

An adapted wiring on the different HSC input allows to:
- Save the exposure time measurement register at the negative transition from the optical fork signal,
- Set to 0 the exposure time measurement register at the positive transition from the optical fork signal.

3.2.1.2 Internal Calibration Light Source (ICLS)

In order to have an easy tool to check the CCD detectors and their readout electronics during the lifetime of the camera, we have designed a light source and an electronic control interface. The calibration procedure could be run during the day between night observations without special system to install. This source will be used for two main purposes:
- Check the linearity of the CCDs
- Reference for trend analysis and monitoring of the system stability

In any case, this source will not be used as a photometric standard source, neither as a flat or pseudo-flat field source.
The light source is made by an array of LEDs which gives an illumination of the whole CCD mosaic. This array is implanted on the internal face of the shutter, i.e. in front of the CCDs. The connection with the control interface is set, when the shutter is closed, by four contacts located on the edge side of the shutter disk.
The illumination of the CCD mosaic is obtained by applying to the LED array a pulse train where the number of pulses is proportional to the light flux desired. The pulse train is set and controlled by the shutter RPLC with an other HSC (same card type that the ETM with a frequency setting of 1 kHz). In order to have a good linearity of the system, the LED array pulse is controlled by an optical feedback directly implanted on the side of the array.
The HSC counter provides one pulse signal with an internal oscillator set by software configuration at the value of 1 kHz. A digital output stops sending the pulses after the requested number of pulses is reached.

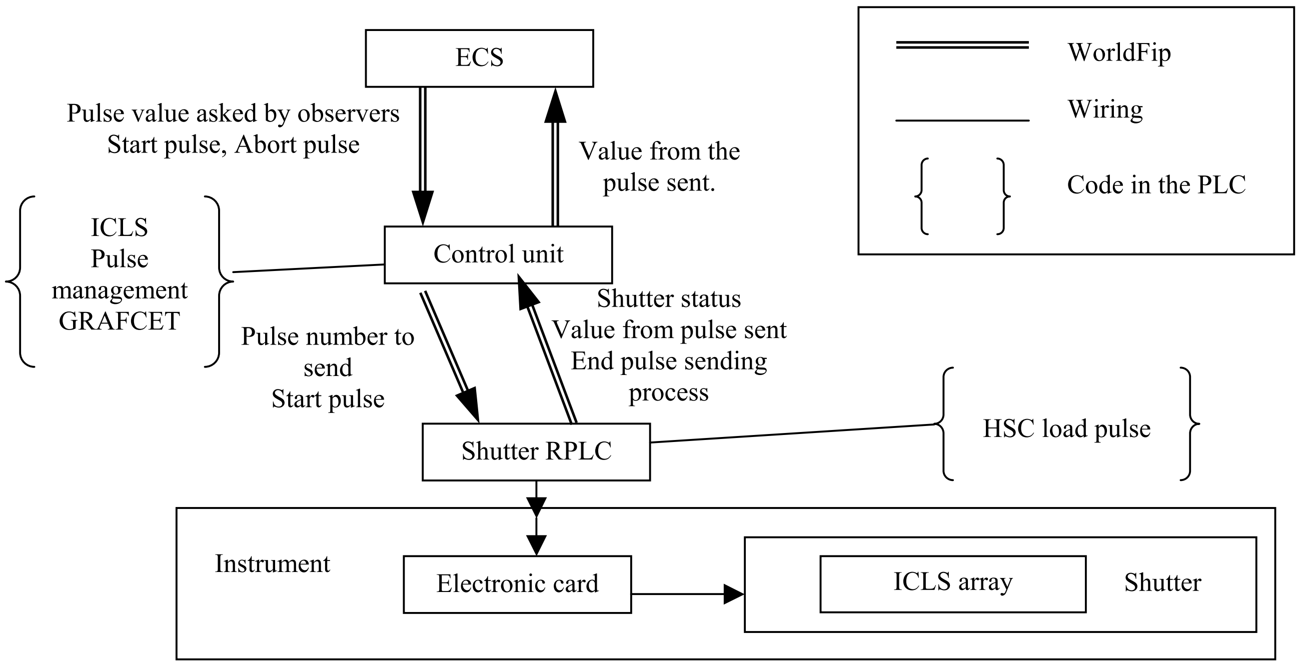

Figure 11 : ICLS management

3.3 Filter Sub-system

The 8 filters installed into the Juke-Box are identified with an inductive system. This technology has been chosen because it does not use optical technology like bar code, it has a good resistance to the telescope environment (humidity, dust and temperature), and it allows to write 256 bytes on each tags.
It is composed of tags fixed on each filter holder, an antenna fixed on the MegaCam structure and a remote device put near the antenna. The filter RPLC is connected to this device through a RS485 link with a JBUS protocol.

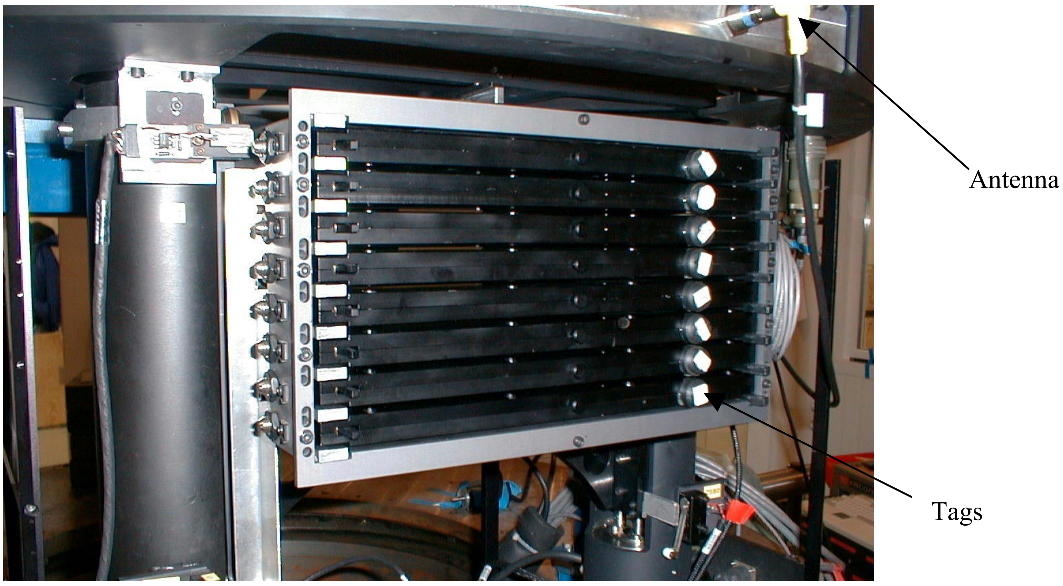

Figure 12 : The filter tags and the antenna

4 ECS

The ECS is a Supervisory Control and Data Acquisition (SCADA) that has been developed since the 90's at CEA Saclay. At the beginning of the development, it ran on DOS OS and since 1997 it is available through an Internet interface, using a remote connection and then a local connection.
The ECS main functionalities are:

- **User interface** : allows to display all the data statuses and send observer and engineering commands to control the MegaCam instrument,
- **Slow Acquisition** : all the MegaCam data are saved on a hourly .csv file (readable on Excel) with an acquisition period set to 30s. This value can be adjusted between 10s and 30s in function of the running process. It creates for one turnaround week. At the end of each day, one acquisition file is made with all the daily data for one year.
- **Historic** tools are provided to analyze the acquisition data using the same view as the user interface.
- **Http server** to access to the same user interface in remote display through PC station with IE 5.

The ECS is connected on the WorldFIP fieldbus and reads the same WorldFip frame than the VME station.

The ECS is composed of:

- **FieldBus Interface ("FBI") software**: it is the real time data server which runs on Windows NT. This software realizes the interface with the WorldFIP fieldbus and the display for all the alarms and warnings on the logged messages view. These logged messages allow to have a quick view of the instrument state. The connections with **FBI** are TCP sockets. Protection must be done by firewall software.
- **Anibus software** : it is a JAVA applet which runs only inside Microsoft's JVM and Internet Explorer. This software realizes the user interface, the acquisition and the historic functionalities. It is a software engine which displays graphic files with standard PCX format. It overrides background image with numeric, bar graph or trend values for analog data and dynamic text fields or palette color commutation for digital data.

Graphical effects are described inside attribute blocks define with the AutoCAD software and convert in a zip file by an other CEA software. The advantage of this procedure, for the production of displays, is to have a light file to transfer when using a remote connection.

- Http server which allows the remote connection on the ECS.

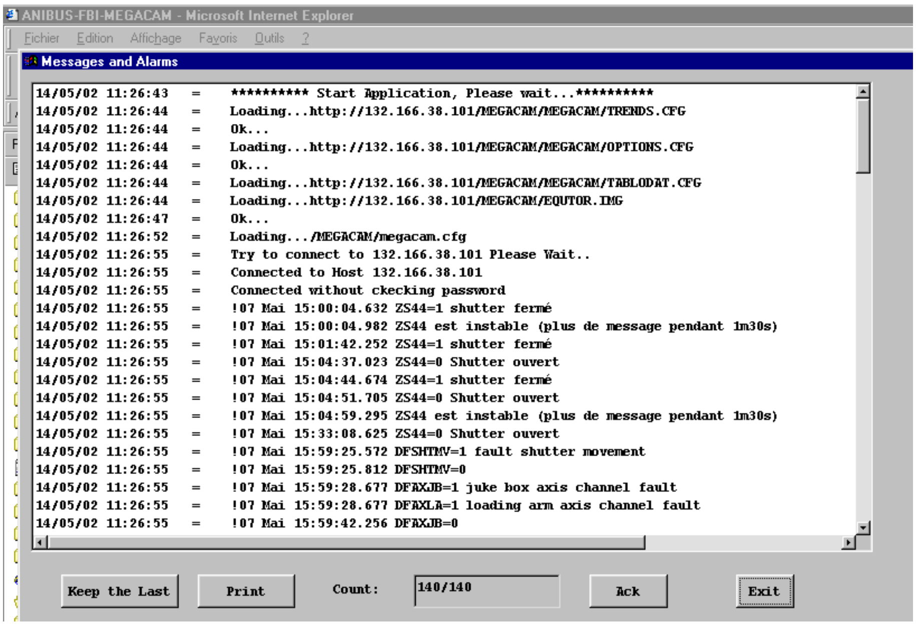

Figure 13 : Messages and alarms views.
This window shows the message and alarms views. The date and time at the left from this view, corresponds to the actual time. The middle date and time corresponds to the message since the last connection. The ECS designer sets the message texts.

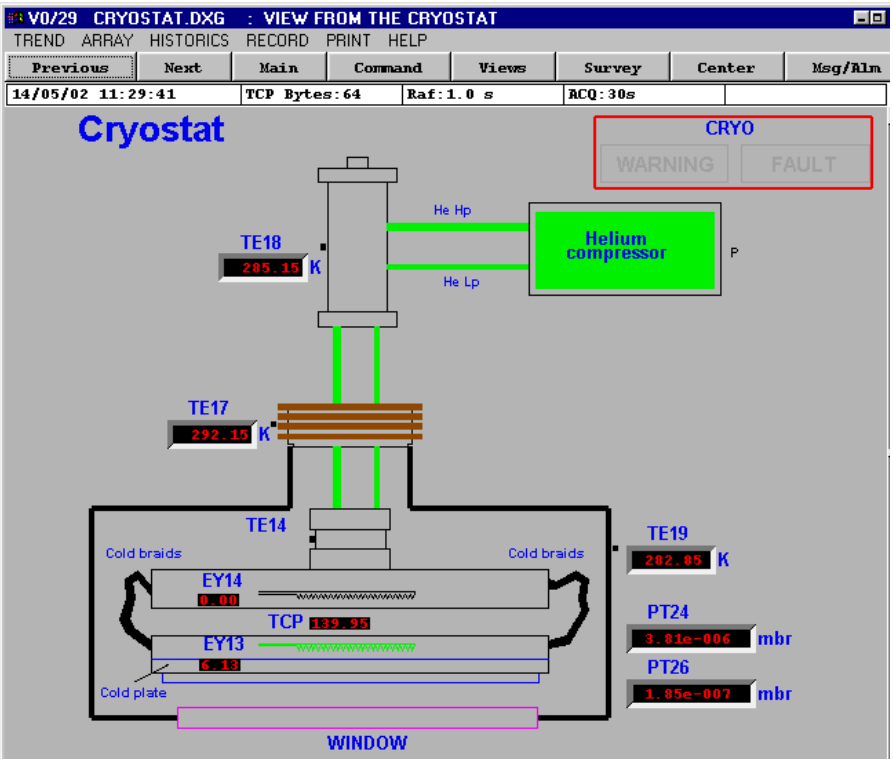

Figure 14 : Example of a MegaCam view. This window is an example of one view of the cryogenic status and its representation on an easy-to-read view.

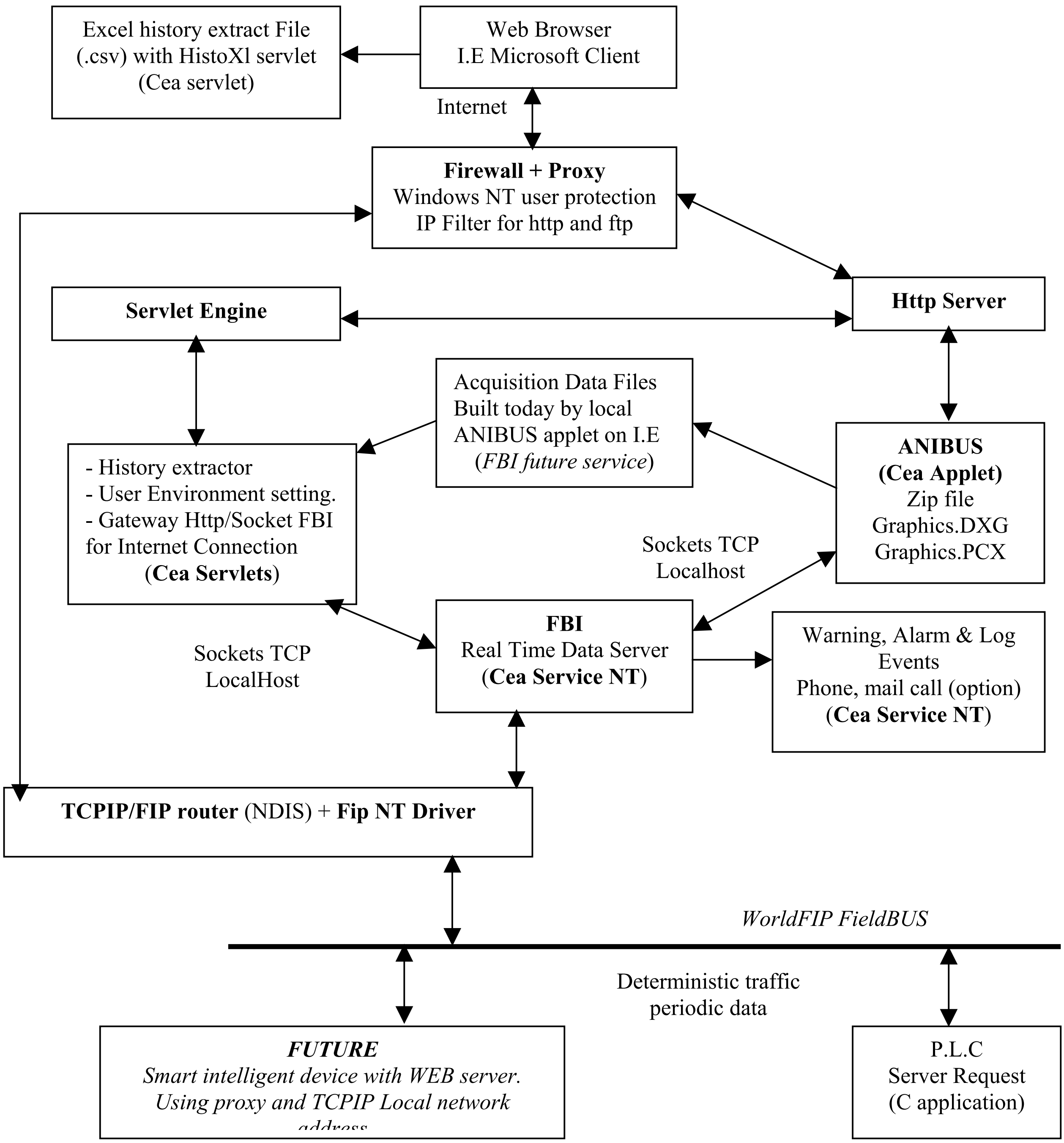

Figure 11 : Today and futur data traffic in **ECS ANIBUS-FBI**

The above figure shows the arrangement of the different softwares implemented in the ECS. It shows also the future developments which are planned at CEA.

5 CONCLUSIONS

The control command architecture brings solutions to the MegaCam during the project development. The WorldFip optic fiber allows at the CFHT to move the different sub-system where they want in the telescope building. The softwares developed on the ECS made the debugging and acceptance phase of the MegaCam project easier. These tools will allow to maintain the instrument easily with the remote connection which give the possibility to do diagnosis and troubleshooting. They are also essential in the physical domain which the advanced technologies must be complete understood to make well-designed instrument.
In the next year, the WorldFip characteristics will open the possibility to transport TCP/IP frames through the WorldFip messagerie. So we can deploy WEB traffic on the fieldbus without perturbing real time exchanges. This development will allow to read or load any control system connected to this fieldbus. It will facilitate again the maintenance.

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