Progetto LAUE ï
Una lente per i raggi Gamma

S/W Coding for MGSE alignment and Fine crystal positioning

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1. Document purpose

The document describe the S/W coding philosophy adopted both for the MGSE alignment system and the Crystal Fine positioning as required by Task 2 (SW coding for MGSE Alignment) and Task 3 (SW Coding for Crystal fine positioning) according to the functional requirement document TASI-LAUEGRL-SP-0003) in the TAS-I W.P. ĩEGSE SW for MGSE management coding, integration and testò

1.1. Applicable and reference documents

1. [DA-01] Contratto ASI I/068/09/0 ed Allegato tecnico gestionale;
2. [DA-02] Proposta Tecnico-Gestionale sottomessa ad ASI;
3. [DA-03] Science Requirement (WP 1200, UNIFE-LAUE-RP-01-10);
4. [DA-04] Mechanical Ground Support Equipment (UNIFE-LAUE-RP-02-2010, Issue 2, 2010-06-05;
5. [DA-06] LAUE EGSE Software functional requirements for MGSE management (TASI-LAUEGRL-SP-0003, Issue 1, April 2012);
6. [DA-07] MGSE movement requirement analysis (LAUE-SP-03-12, Issue 1, September 2012;

1.2. Acronyms

ASI	Agenzia Spaziale Italiana
EGSE	Electrical Ground Segment Equipment
GUI	Graphical User Interface
HW	Hardware
IASFBO	Istituto di Astrofisica Spaziale e Fisica Cosmica di INAF Bologna
INAF	Istituto Nazionale di Astrofisica
LARIX	Large Italian X-ray facility c/o Ferrara University
MGSE	Mechanical Ground Segment Equipment
RT	Real Time
SW	Software
TAS-I	Thales Alenia Space -Italia
UNIFE	Università di Ferrara ï Dipartimento di Fisica
WP/WPD	Work Package/Work Package Description

2. Introduction

This document in the first chapters (3-4) give an overview of the MGSE system implemented at the LariX beam facility in the framework of the Laue project [DA-02, DA-3]. The MGSE functions have been defined in [DA-04] to allow both the correct positioning of each crystal tile on the Laue lens demonstrator support and the performance tests on the final Lens petal under X ray beam irradiation. The Laue MGSE consists of two main components: (a) the MGSE alignment system and (b) the Crystal fine positioning system.

In the chapter 5 and 6 this document describe the Software developed to manage and operate respectively the MGSE alignment system and the Crystal Fine positioning system.

In this document we adopt the reference system established in the MGSE definition document [DA-04]: the X-axis is in the direction of the LARIX tunnel axis (all the movement along this direction are manual and are not considered in this document); the Y axis is across the horizontal direction of the tunnel section (the range along this direction is ~60 cm), while the Z axis represent the vertical direction in which a movement range of ~60 cm is allowed. Furthermore are defined three rotational axis characterized by corresponding angles: ű represent the rotation around the X axis; ď is the rotation around the Y axis, and ŭ the rotation around the vertical direction (Z axis).

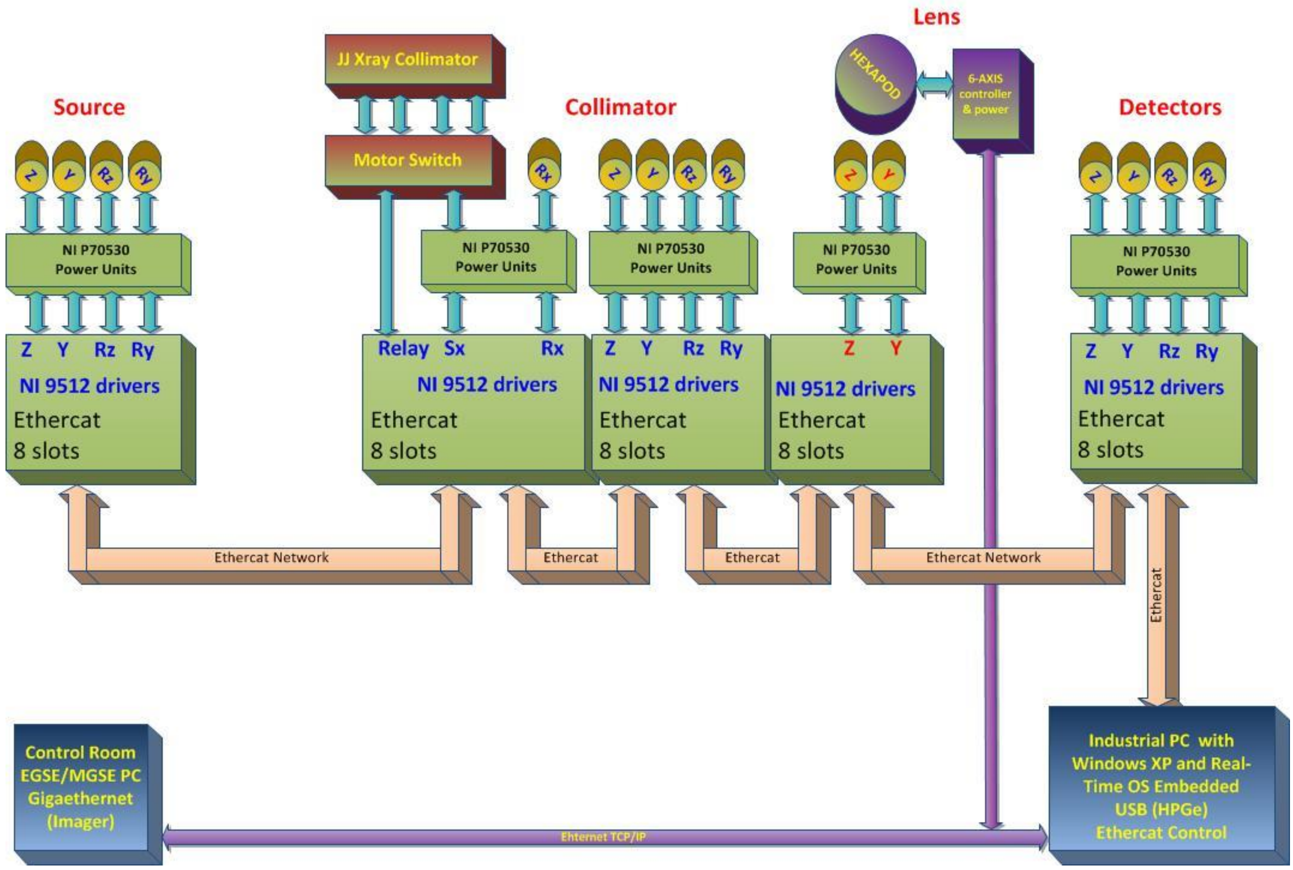

Figure 3.1. *The MGSE system configuration implemented at the Laue LARIX beam facility.*

3. The MGSE alignment system and the Crystal fine positioning system

Following the requirements defined in [DA-04] the MGSE alignment system that will be built for the LAUE project at LARIX is composed by the different subsystems as summarized in Table 3-1 and visualized in the scheme in Figure 3.1:

Subsystem	Relevant Movement Axis
Source This subsystem includes the X-ray source and the first (Pd/W) collimator fixed with respect to the source itself	2 translations (Y,Z); 2 rotations (đ,ŭ)
Collimator A 4 tungsten (W) slits collimator on a movable mechanical support	2 translations (Y,Z) for the support; 3 rotation (ű,đ,ŭ) 4 translations (2xX and 2xY) for the collimator W slits. These 4 motors are built in.
High precision actuator support The movable support of an Hexapod system.	2 translations (Y,Z). *The Hexapod axis (6) are managed by an independent system.*
Focal plane detectors This subsystem includes the Imager and the Spectrometer detectors.	2 translations (Y,Z); 2 rotations (đ,ŭ)

Table 3.1 The MGSE sub-systems

The Crystal fine positioning system implemented in the Laue LARIX beam facility is based on an Newport Hexapod device. This type of high precision actuator is able to handle 6 movement axis (3 translations along the axes of the XYZ reference system and 3 rotations, one around each axis of the same reference system. The Hexapod 6 degree of freedom movement is realized through 6 built-in linear motor stages. The Hexapod is integrated in the MGSE alignment system through the ñHigh precision actuator supportò subsystem that provide the mechanical interface between the two systems.

3.1. Main MGSE alignment characteristics

To determine the performance required of motors to be used in the various MGSE subsystems, calculations were performed that took into account the load, the friction and the yields of all the moving parts on each axis. In particular to obtain the values summarized in Table 4-1, in this analysis, only the worst case has been considered.

For the translation stage the movement along the vertical Z axis for the Source subsystem was considered, while for rotations the rotation around the Y axis for the same subsystem has been taken into account. In fact, the subsystem of the source have the greater load (the first collimator in Pb / W) to be translate and the one with the greater moment of inertia to be rotated due to the particular distribution of the masses. Therefore the values of the motors couple values reported in Table 4-1 represent the maximum required and the most conservative values.

In addition to the required strength couple, the second motors main characteristics to be evaluated was the precision required to guarantee the positioning error of all the MGSE components within the allowed error budget established in [DA-03]. For the rotation stages the required precision is 5ῃ while for the translation ones is 10 µm.

Table 3.2. Motors and mechanical accessories requirements and specification summary

Translation stages	Max. Couple=0.8 Nm	Precision= 10µm
Rotation Stages	Max. Couple=0.3 Nm	Precision= 5ῃ
Mechanical Gear reduction (all stages)	1:160 with an efficiency of 0.6	
Endless screw (translation stages)	20 mm Ø, 5 mm step, 1000 mm length	

Taking into account the common characteristics implemented in each axis and to fulfil the motor requirements we have proposed the following motors type for all the relevant axis:

- Stepper motors: T23NRLH-LDN-NS00 (National Instruments)
  This type of motors are low power consuming and low cost. As standard this stepper motor have 200 steps/360°, i.e. 1.8° per step. This feature in conjunction with the characteristics of the adopted gear and endless will allow to reach the following precisions:
  - **Translation: φ= 5 mm** (endless screw step)/200 (steps)/160 (gear reduction) = 1.5 µm
  - **Rotation: φ= 1.8°** (degree per step)/160 (gear reduction) = 41"

All the MGSE linear movements are defined within the nominal range between ± 300 mm; while the effective range will be defined by its hardware limits (see section 4.1)

The rotation stages does not have a predefined range, because they are free to turn over 360° for construction, even if rotation movements are expected to be limited within at maximum few tens of degree during operations. In effect the physical limits of each rotation stage will be defined later depending on mechanical and hardness constraints on each MGSE subsystem.

3.2. Main Fine crystal positioning system characteristics

In the Laue X-ray beam facility the device devoted to the crystal fine positioning on the petal support is a Newport Hexapod (Model HXP-MECA 100) unit. A Hexapod is a parallel kinematic motion device that provides six degrees of freedom: X, Y, Z, pitch, roll, and yaw. Hexapods are ingenious and effective solutions to complex motion applications that require high load capacity and accuracy in up to six independent axes.

Table 3.2 Hexapod HXP-MECA 100 main characteristics

	X	Y	Z	Ūx	Ūy	Ūz
Travel range	±29 mm	±16 mm	28 mm (-1 to +27)	±12°	±10°	±20°
Minimum incremental motion	0.5 εm	0.5 εm	0.25 εm	0.00025°	0.00025°	0.0005°
Uni-directional repeatability, typical	0.5 εm	0.5 εm	0.25 εm	0.00025°	0.00025°	0.0005°
Bi-directional repeatability, typical	4 εm	4 εm	2 εm	0.002°	0.002°	0.004°
Max. speed	2 mm/s	2 mm/s	1 mm/s	0.8°/s	0.8°/s	1.6°/s
Stiffness	5 N/εm	5 N/εm	40 N/εm	ï	ï	ï
Centred load capacity	200 N					

4. MGSE alignment s/w functional scheme

On the basis of the MGSE movement analysis [DA-06] we have proposed the implementation described in Figure 3.1, where all the MGSE subsystem in the new LARIX beam facility are represented with their own required axis (movement stages).

The driving adopted philosophy is to have the maximum modularity of the system coupled with simplicity in the interconnection between all the MGSE subsystems and the EGSE system. This configuration allow to minimize the cabling required to handle the overall MGSE system by an external PC: in fact only one RJ45 cable is required between Ethercat modules, while all the heavy hardness (motor power and drivers cables) is physically concentrated in each MGSE subsystem.

In the proposed configuration each relevant axis stage in any of the MGSE subsystems (identified in Table 3-1) are operated through one/or two Ethercat modules that are connected to one another in series and operated by an industrial PC.

The industrial PC, which will be located inside the beam facility on the focal plane detector mechanical support, will run in parallel both a real time environment (Labview RT) and Windows XP. The RT environment will be used to handle each MGSE axis/stages through the Ethercat network, while the Windows XP environment will be used to control and read both the Imager and the Spectrometer data using the GigE and the USB interface.

The industrial PC is then connected to the EGSE workstation located in the Larix control room using a standard TCIP connection. All the processes running on the industrial PC can be accessed through high level GUIśôand/or by remote control windows.

The proposed MGSE movement scheme is based on National Instruments components and all the relevant s/w tools and/or GUI are developed in the Labview environment. All the adopted components are summarized in the following Appendix A.

5. MGSE alignment s/w coding

The MGSE alignment system software for the Laue project is developed in the LabView 11.x environment. Figure 5.1 represent the logical separation between S/W functions implemented under the RT and Windows environment.

The s/w package is constituted by a LabView project running on the industrial PC and one on the EGSE console in the control room, connected together via Packet Socket on Ethernet.

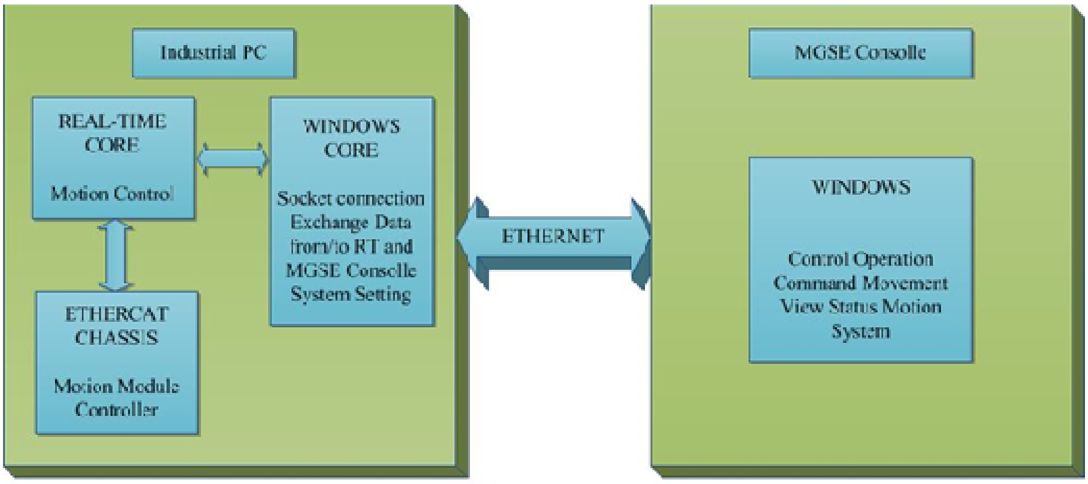

Figure 5.1. *Block diagram logical separation between S/W functions implemented under RT and Windows environment running in the industrial PC.*

5.1. The general S/W flow: tasks subdivisions and related Labview tools

The Labview project (Motore0.lvproj, see Appendix A) on the Industrial PC includes the management of the Windows and Real-time cores by using global variables to exchange data using a defined Virtual Internet network.

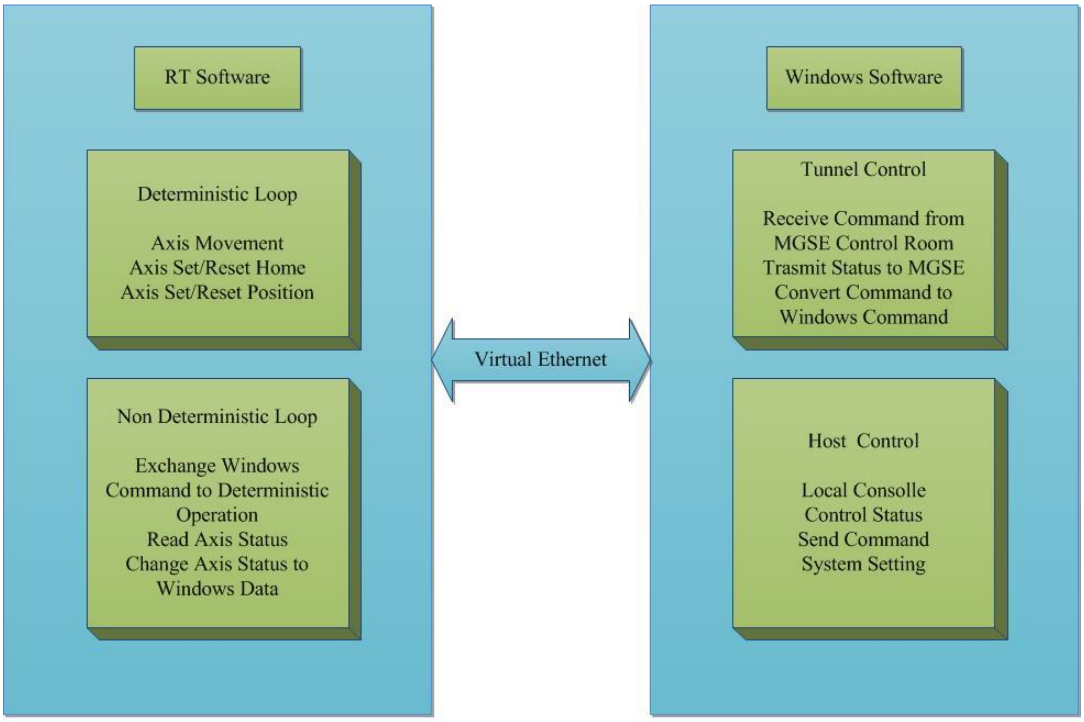

Figure 5.2. *Flow diagram of the S/W running in the Industrial PC*

The Windows Labview project section contains a procedure (Tunnel_control.vi, see Figure 5.3) that allows the socket connection with the EGSE/MGSE console. This procedure manage and control the decoding of the incoming packet from the console in operating commands for the RT system as well as the packaging and the sending of MGSE status information to constantly update the console displayed parameters.

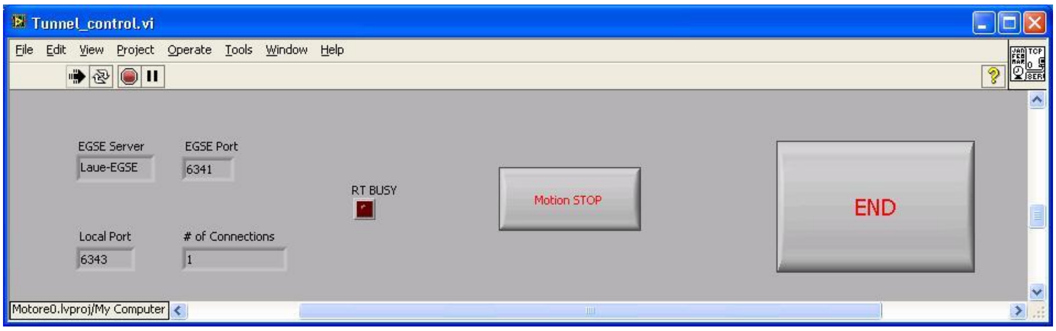

Figure 5.3. *The Labview front panel of the Tunnel_control.vi tool that allow the definition of the Industrial PC/EGSE socket connection parameters and the control of its operation status.*

A second program (host-Control-RT.vi, see Figure 5.4) of the Labview project, allows a local console for the complete management of all MGSE movements that can be operated individually on each axis and/or in parallel over MGSE subsystems. This program and its user interface enable the management and control of operations during the development and alignment of the Laue system. The use of this procedure, during the phase of construction of the lens is not necessary.

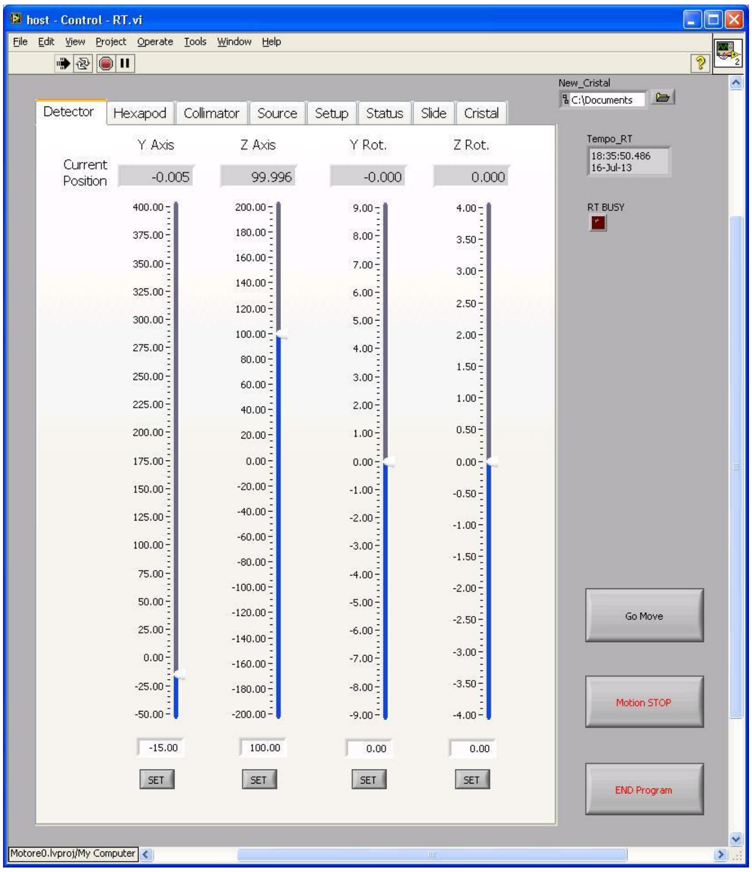

Figure 5.4 *The front panel of the host ï Control ï RT.vi tool that allow the management and the operation of each MGSE movement stage by means of numerical controls divided (panel tabs) by the MGSE subsystems.*

The two programs, in case of need, can operate in contemporary because they work accessing the same global variables of the system.

5.2. Labview movement (RT Program) handling tools

One section of the Real-Time Project is represented by the program that allows to operate the individual movements, which are distributed on different EtherCat chassis. Each EtherCat module comprising the intelligent control units for each motor driven by the program. The EtherCAT protocol is a synchronous management of distributed intelligence in a defined sequence over the Ethernet network.

The program provides for the definition of a axis for both each movement (motor stage) and a cluster of axes to be able to associate in addition to the properties defined for each axis also the specific properties for the relative movement (e.g. speed of Linear/Rotation movements, Home values, Last reached position, etc ...). The movement of the axes is performed in a synchronous manner between the subsystem towers distributed along the X-ray facility tunnel. This tool provide to constantly save reached position values for each axis/stage.

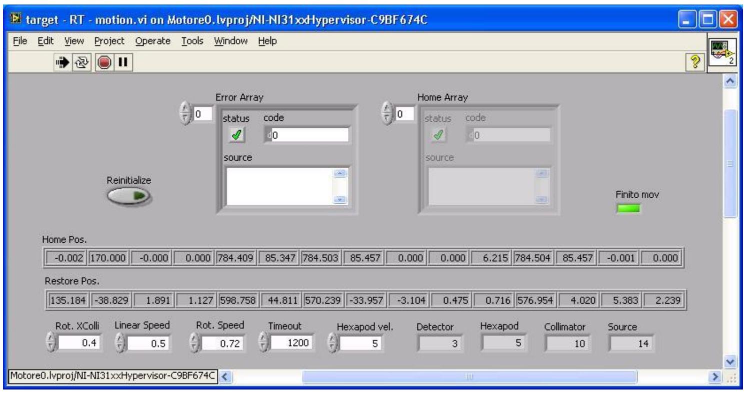

Figure 5.5. *The front panel of the Labview tool implemented to define and handle properties of each axis/movement stage. In this panel there are shown the definition of home and restore position values and the common movement parameters for all the implemented axis.*

The Real-Time process consists of two loop running concurrently, one is called "deterministic" because it is associated with each operation on the defined axes and therefore is synchronous with the EtherCAT modules. The second named ñnon deterministic" provide the connection with the processes running under Windows.

The ñnon deterministicò process translate incoming requests from Windows processes, through the Global Variable in RT variable (FIFO) for the deterministic loop, reads and transfers the state variables and position for each axis in global variables accessible by the EGSE console.

The deterministic process in response to the received requests perform the operations by the dividing them into different but functionally identical operations (subVI) to allow the contemporaneity in addition to the synchronization of the axis movements on different MGSE subsystem. For each axis the process controls and returns the MGSE system state, the current location of each axis, the Home position, the s/w and the h/w limits, and also provide the general state of the commands execution.

5.3. Laue petal map

Il processo LabView che consente il controllo completo della gestione dei movimenti durante la fase di realizzazione della lente che nella fase di test. Una volta connesso con gli socket al PC industriale il programma visualizza lo stato di tutte le componenti allôinterno del tunnel, e permette la gestione delle operazioni. Vi sono presenti due finestre di visualizzazione e un gruppo di finestre di controllo. Le finestre di visualizzazione sono: una per la rappresentazione grafica del petalo, lôaltra per la rappresentazione completa dello stato del sistema, posizione e stato di ciascun asse. Le finestre di controllo permettono di: montare i cristalli, posizionare i rivelatori, resettare la Home, mettere un offset al fascio su un cristallo, resettare eventuali Fault, muovere le slide del collimatore e test della lente.

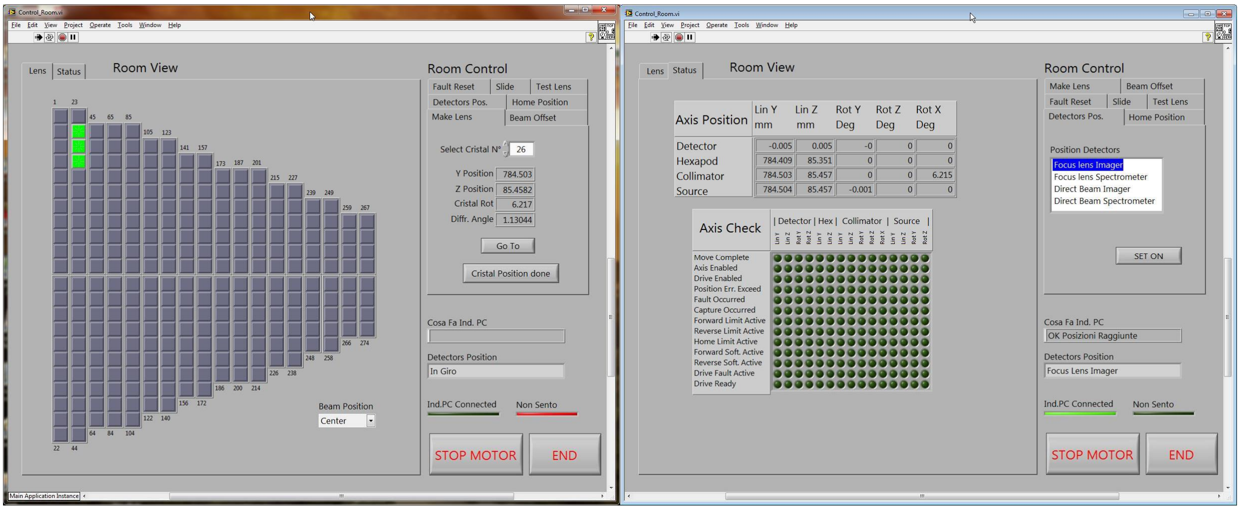

Figure 5.6. The two main tab panels of the Control_Room.vi

Per la realizzazione della lente è possibile selezionare, via via, il cristallo da montare tramite una finestra dedicata e con la visualizzazione grafica dello stato del petalo e della posizione del cristallo stesso. Questa selezione viene controllata e/o in caso di variazioni sulla procedura prevista, vengono visualizzati allôutente, delle finestre di Warning, con dei messaggi di attenzione. Una volta selezionato il cristallo desiderato con un semplice pulsante si invia a tutto il sistema le informazioni necessarie perché si posizioni in modo corretto. Inoltre compare un Warning per ricordare allôutente i valori iniziali per quel cristallo da inserire nella finestra di controllo dellôHexapod.

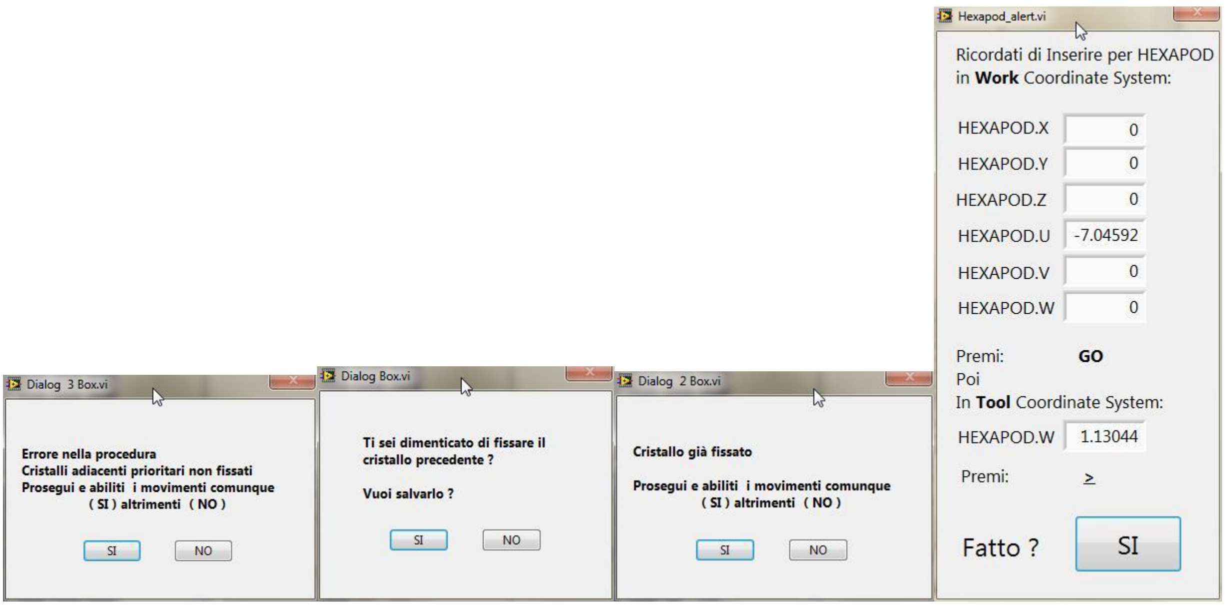

Figure 5.7*. The warning Dialog boxes generated by the Control_Room.vi tool when passing from one crystal to another.*

6. Fine crystal positioning s/w coding

Description of the Hexapod s/w and related Labview tools.

7. Appedix A: MGSE alignment s/w coding: Labview sources examples