OBJECT ORIENTED SOFTWARE FOR SIMULATION AND RECONSTRUCTION OF BIG ALIGNMENT SYSTEMS

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1. INTRODUCTION

Modern high energy physics experiments require tracking detectors to provide high precision under difficult working conditions (high magnetic field, gravity loads and temperature gradients). This is the reason why several of them are deciding to implement optical alignment systems to monitor the displacement of tracking elements in operation.

To simulate and reconstruct optical alignment systems a general purpose software, named COCOA, has been developed, using the object oriented paradigm and software engineering techniques. Thanks to the big flexibility in its design, COCOA is able to reconstruct any optical system made of a combination of the following objects: laser, x-hair laser, incoherent source - pinhole, lens, mirror, plate splitter, cube splitter, optical square, rhomboid prism, 2D sensor, 1D sensor, distance-meter, tilt-meter, user-defined. COCOA was designed to satisfy the requirements of the CMS alignment system, which has several thousands of components. Sparse matrix techniques had been investigated for solving non linear least squares fits with such a big number of parameters.

2. CMS OPTICAL ALIGNMENT SYSTEM

The muon chambers in CMS have an internal precision of 200 μm, but they will suffer movements and deformations from magnetic field, gravity and temperature up to 2 cm. For this reason, an optical alignment system will monitor continuously its position with a precision of 150 μm.

This system is in fact composed of four subsystems:

- The internal alignment of the barrel muon chambers, based on incoherent light sources that pass through pinholes and end in two-dimensional sensors, plus distance measurements.

- The internal alignment of the end-cap muon chambers, based on x-hair lasers rays that hit boxes of four one-dimensional sensors, plus distance measurements.
- The internal alignment of the central tracker detector, based on laser rays that hit several semitransparent sensors, plus distance and tilt measurements
- The link between the muon chambers and the central tracker detector, based on laser rays that hit several optical objects (rhomboid prisms, splitters, mirrors, optical squares) and end traversing several semitransparent sensors, plus distance and tilt measurements.

3. DESCRIPTION OF THE ALIGNMENT PROBLEM

Due to the unknown movement of the objects, the sensors of the optical alignment systems will not provide the expected measurement values. The aim of the software is to analyze the change in the measurement values and to be able to determine which are the changes in position or rotations of the objects or in the internal calibration of these objects that caused the measurement changes.

The approach adopted by COCOA [1] to tackle this problem is to solve the system of equations that relate the measurements values to all the positions, rotations and internal parameters of all the objects that make the system. In fact, to solve the system of equations, one does not need to know the explicit form of the equations, but only the derivatives of each measurement value with respect to each object parameter. COCOA uses a geometrical approximation of the propagation of light to calculate numerically these derivatives and then solves the system of equation through a non-linear least squares method. Due to the big number of parameters in CMS (about 30,000), big sparse matrices are needed. COCOA matrix manipulations are based in the meschach [2] library.

4. COCOA

COCOA is general purpose software to simulate and reconstruct optical alignment systems composed of any combination of

laser, x-hair laser, incoherent source / pinhole, lens, mirror, plate splitter, cube splitter, rhomboid prism, optical square, sensor1D, sensor2D, COPS, distance-meter / distance target, tilt-meter

Each object may have internal parameters (planarity of a mirror, wedge between plates of a plate splitter, ...). Moreover, the user can define its own object by providing a brief text description of how much the light ray will be shifted and deviated for each measurement.

The user must only describe its system in an input ASCII file with a clearly documented format, and select which parameters are known and which unknown. COCOA will then reconstruct the positions, rotations angles and internal parameters of the objects that build the system and will also propagate the errors of the measurements and the calibrations.

To read the measurements from a DAQ system, COCOA provides an interface. To facilitate the analysis of results, COCOA provides and interface to make histograms of measurements and results. It is also possible to make an automatic scan of a parameter and analyze the results.

Interactive three-dimensional visualization of the system components and the light paths is possible using VRML (Virtual Reality Modeling Language).

COCOA has been developed as a Software Engineering project. First the User Requirements were collected and then an spiral approach has been used to improve the design and code. The documentation is a main priority of the project. It currently provides a Primer, a User's Guide, an Advanced User's Guide, two examples explained with detail, plus the UML (Unified Modeling Language) class and sequence diagrams and the API (Application User Interface).

4. USE OF COCOA

COCOA has proved its robustness through its extensive use in CMS for several design studies, as well as for analyzing the results of several test benches. Among the design studies, the most important ones have been the simulation of the whole CMS Link alignment system, with 3,000 free parameters and the whole CMS Muon End-cap alignment system, with 6,500 free parameters. The design of the CMS Muon Barrel alignment system, with 20,000 free parameters is under progress.

Among its use to reconstruct real systems, the biggest one is the test done at CERN with a full plane of the muon alignment system, including almost 1,000 free parameters.

A point still of concern is the big amount of time and memory needed to simulate so big alignment systems: the 3,000-parameters CMS Link alignment system takes 31 minutes in a Pentium III 850 MHz and consumes 590 Mb of memory. The possibility of breaking the system in pieces, and diminishing the number of free parameters is under study.

4. REFERENCES

[1] *COCOA*. http://cmsdoc.cern.ch/cms/MUON/alignment/software/COCOA.

[2] *Meschach sparse matrix library*. http://www.meschach.com