COCOA: CMS Object-oriented Code for Optical Alignment

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Abstract
COCOA is a C++ software that is able to reconstruct the positions, angular orientations, and internal optical parameters of any optical system described by a seamless combination of many different types of optical objects. The program also handles the propagation of uncertainties, which makes it very useful to simulate the system in the design phase. The software is currently in use by the different optical alignment systems of CMS and is integrated in the CMS framework so that it can read the geometry description from simple text files or the CMS XML format, and the input and output data from text files, ROOT trees, or an Oracle or MySQL database.

22.1 Introduction

When analyzing an optical alignment system, there are several problems that the software must help to solve. In the first stage the work of the software concentrates more on what we can call the 'simulation' part. This means describing the different system designs to study the performance of each option, given by the total error propagation, the redundancies of measurements, or the range of displacements and rotations. In a second phase the software is mainly used for 'reconstruction'. This means being able to deduce from the measurement values which objects of the system have changed their position, rotation, or their internal calibration.

COCOA [1] has been written to help with both of the tasks described above (the only real difference being that in the first case the measurements are simulated and in the second they are real).

22.2 Description of COCOA

COCOA is a general-purpose software that can 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 [2], distance-meter / distance target, or tiltmeter.

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

The user only needs to describe his 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, rotation angles, and internal parameters of the objects that make up the system, and will also propagate the errors of the measurements and the calibrations.

To solve the system, COCOA needs to know the system of equations that describe how each measurement depends on each of the parameters: positions, rotations, and internal parameters of each object. Indeed, to solve a system of equations, it is not necessary to know them, but only the derivatives are needed. COCOA obtains the derivatives with a numerical method:

1. reproduces a measurement with initial parameters (e.g., propagate a laser until the sensor);
2. moves a parameter and sees how the measurement value changes;
3. repeats n times steps 1 and 2, until they converge.

As most of the equations are non-linear, the system is solved iteratively.

Given the total number of parameters needed to describe the CMS optical alignment system — about 40 000 parameters — big matrices are needed. Fortunately these matrices are usually quite sparse. For helping with the management of these big matrices, a sparse matrix library, the **meschach C library**, is used [3].

COCOA is currently fully integrated in the CMS software, although it can also be run as a stand-alone application.

22.3 Input and output

The first thing you should do to use COCOA is describe your set-up. This can be done in a simple text file or using the CMS XML detector description format [4]. Once your system is described, you should select which of the object parameters are unknown and which are known. For those that are known you should write the best knowledge of their values. These values can be written in the set-up text or XML description file, or they can be read from another text file or from a MySQL or POOL-ORA [5] database.

To input your measurement values to COCOA, you can use a simple text file or a ROOT tree in a well-defined format.

The output of COCOA, i.e., the new values of the object parameters, as well as the errors and their correlations, can be given in a text file or in a MySQL or POOL-ORA database. As COCOA is integrated in the CMSSW software, this output can be used not only as input to a new COCOA run, but also as input for the alignment with tracks. Inversely, the output of the alignment with tracks can be used as a starting point for a COCOA run.

To visualize your detector you can produce a VRML (Virtual Reality Modeling Language) file, or use the CMS IGUANA [6] visualization of XML files.

22.4 Time and memory consumption

To analyse the full CMS alignment system, a system of around 40 000 parameters has to be solved, which represents a big challenge for the software. As an example, the full CMS Link alignment system, with 2865 parameters, takes around 30 minutes in a Pentium III 850 MHz, and occupies a memory of 590 Mb. As the time increases as the third power of the number of parameters and the memory as the second power, it seems clear that other approaches have to be investigated for the full CMS system.

Several solutions are at present under study:

- *Diminish the number of parameters*. Many parameters have a negligible effect in the final result and could be set to be fixed, so that they would not appear in the system of equations. However, this option needs careful case-by-case testing to avoid biasing.
- *Split the system in N parts*. There is no really independent subsystem, but the system may be split into several parts if the correlations between the different blocks are properly taken into account.
- *Use other library packages*. Other library packages, with different approaches, such as Millipede II, could help solve the problem.

22.5 Use of COCOA

COCOA has been extensively used in CMS for several years. It was used first to do most of the design studies that defined the current CMS optical alignment system.

It has also been used for designing and analyzing the data of several test benches of the CMS optical alignment system.

The full CMS Link alignment subsystem (3000 parameters) and CMS Muon End-cap alignment subsystem (6500 parameters) have been successfully simulated with COCOA.

COCOA has also been used to reconstruct some subsets of the full CMS alignment system. Amongst these we can cite the test in 2002 of a full CMS muon alignment half-plane, with more than one thousand reconstructed parameters. Also COCOA was used to simulate a third of the full CMS optical alignment system at the 2006 CMS magnet test, and its data is being analyzed.

COCOA will also be the software used for analyzing the CMS optical alignment data and passing the alignment correction to the CMS reconstruction software when the LHC starts taking data.

References

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

[2] J. Moromisato *et al.*, *Nucl. Instrum. Methods* **A426** (1999) 375–384.

[3] `http://www.meschach.org` .

[4] `http://cmsdoc.cern.ch/cms/software/ddd/www` .

[5] `http://pool.cern.ch` .

[6] `http://iguana.cern.ch` .