THREE YEARS OF
DIGITAL PHOTOGRAMMETRY AT CERN

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1. INTRODUCTION

The LHC (Large Hadron Collider) is the new particle accelerator project at CERN (European Laboratory for Particle Physics) in Geneva. It will be a 27 km long accelerator made of super-conducting magnets. Four big physics detectors: ALICE, ATLAS, CMS, LHC-B, will be installed at four points around it. With this project, new survey requirements appear together with new spatial and time scale constraints.

In order to respond to the demand, the CERN Positioning Metrology Group decided to expand its tool box by buying digital photogrammetric equipment three years ago. Basically this equipment consist of Kodak DCS460 cameras and of the Rollei-CDW (Close-range Digital Workstation) software. This system has been used quite extensively since its purchase.

The next chapters illustrate the reasons for the choice of the digital photogrammetry tool at CERN and the evolution of its use. Some adapted tooling is also described below.

2. JUSTIFICATION OF USING THE DIGITAL PHOTOGRAMMETRY

The choice of the digital photogrammetry by the CERN survey group is directly linked to the survey needs of the new experiments and the related constraints.

The survey measurements are needed for positioning, deformation analysis, geometrical calibrations and for the crucial dimensional quality controls.

The general performance of the new LHC experiments implies a very good precision of their geometrical parameters knowledge. The precision requirements for the object co-ordinates vary from 0.05 mm for medium size objects up to some tens of millimetres for large size ones.

It appears to be difficult or impossible to install a dense micro geodetic network near the measured objects and consequently the work cannot be done using only standard survey methods.

The geometrical relationship between the different sides of the detector or sub-detectors is essential in most of the cases and the objects have to be measured in their entirety. This implies station positions all around the object and common extra-points of good quality.

The measurements can take place either in factories or in different locations at CERN with a regular frequency. The environment is such that the free and available space around the objects is generally small and cramped. Large objects, 15 to 20 m high, have to be measured at a distance of only a few meters.

During the installation, services and cables will be installed on the detector modules and will multiply the number of obstacles.

The measurement time, mainly for data acquisition, has to be short :

- to interfere as little as possible with the schedule, especially in factories or during the assembly phases at CERN;
- to be able to provide similar measurements on a large number of sub-detector modules, such as for the geometrical quality control of detector components;
- to be able to repeat similar measurements of a same object during a short period, for example for deformation measurements.

All these constraints justify the use of the precise and versatile tool that digital photogrammetry is, by a skilled team composed of a reduced number of persons in the field.

3. THE EVOLUTION OF THE USE OF PHOTOGRAMMETRY AT CERN

In 1996 the main work was to perform acceptance and training tests. This first experience was helpful to answer some basic questions like :

- how to choose the camera configuration such as the right focal length, the right camera setting?
- how to take the pictures to have a good geometrical configuration compatible with the digital photogrammetric method, including automatic detection of image co-ordinates?
- how to properly link different faces of an object?
- where to place extra targets, scale bars and scaling distances?
- how to improve the precision?

The “true” measurements really began in 1997 when the first medium size prototypes of detector parts appeared, see figure 1.

Then they were extended to larger size objects, such as some dense local geodetic networks: the co-ordinates of a laboratory network for the CMS Barrel Alignment System Test Bench, made of 24 main points covering 7 m x 3 m, were determined with a global precision of 0.05 mm along the three co-ordinate axis.

Tests were done to prepare very large object measurements with the constraint of linking their different faces. A 2/3 scale mock-up of the CMS Barrel Yoke was built. These tests gave a realistic idea of the precision which could be reached and of the effort to achieve it. They highlighted the necessity to use adapted tooling such as large diameter targets for the large distances and spherical ones for the geometrical link of the different faces.

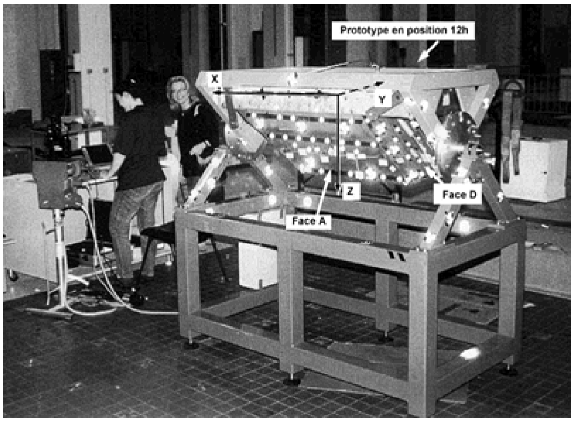

Figure 1 : CMS ECAL Module prototype, deformation measurements, 1997

Today the first of the final detector parts are starting to be measured. For example, each of the five rings of the CMS Barrel Yoke, 15 m diameter x 2.5 m thickness, is followed step by step during its construction in DWG factory in Deggendorf – Germany, see figure 2.

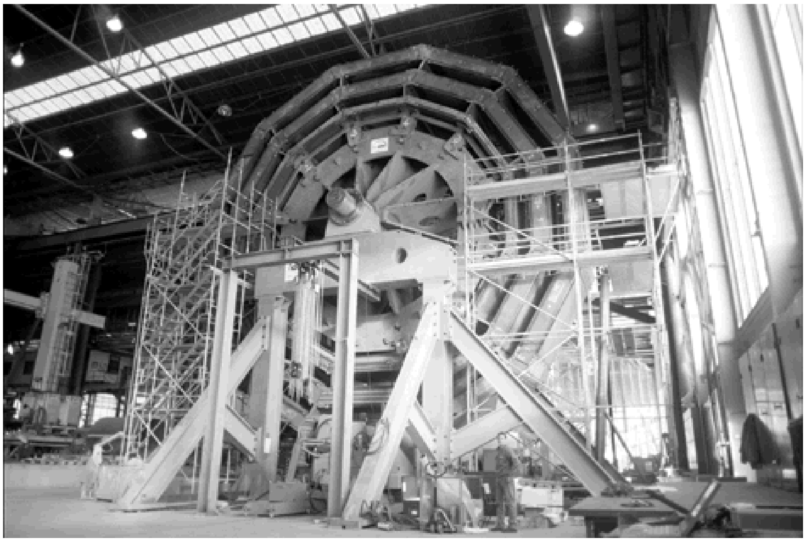

Figure 2 : CMS Barrel Yoke, geometrical validation, 1999

4. SOME ADAPTED TOOLING

To meet the above constraints adapted tools have to be studied and tested in order to shorten the preparation time of the photogrammetric surveys, to improve the quality of the results, and to perform measurements in special conditions such as lack of space for the survey of large sized objects. Some of these tools are described below.

4.1. Spherical targets[(1)]

Their necessity was to answer two questions :

- "How to have the best convergence angle of the pictures to get a good geometrical configuration?";
- "How to make a good geometrical connection between the faces of an object?".

Use of spherical targets proved to be a good solution.

A good configuration for ray intersections is essential. Due to the pattern of a common button target the view angle cannot exceed 30 to 45° from a line perpendicular to the target, otherwise the elliptic image is too "flat" and the point image is not detected. Since the image of the spherical targets is independent of the view angle and is always a circle, the geometrical configuration can be improved by a greater number of possible station positions. This property also allows a good geometrical connection between the different faces of the objects with a reasonable number of pictures.

Two types of spherical targets have been made according to the our specifications.

The first type is a 30 mm diameter spherical target mounted on a magnetic foot. These targets are used as extra points or as connection points stuck on the object side. Their size allows to use them for large object e.g. the CMS Barrel Yoke.

The second type is a 20 mm diameter spherical target, see figure 3, with the following mechanical characteristics :

- 20 mm diameter;
- mounted and centred on the 8 mm diameter axis with a precision better than 50 microns;
- distance between sphere centre and the target base : 35 mm with a precision better than 20 microns;

These characteristics have been confirmed by the CERN Metrology service.

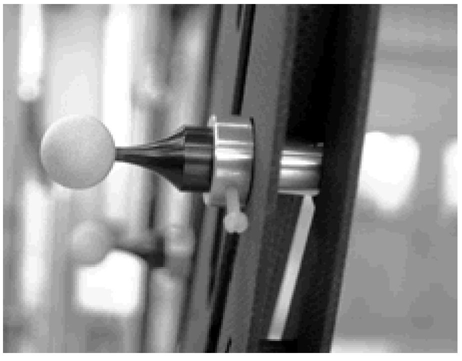

Figure 3 : 20 mm diameter spherical target

Example of use.- A 1.5 m diameter disk with points on both side has been measured with a DCS460 equipped with a 24 mm lens. It shows that the image co-ordinates of the 20 mm diameter spherical targets are detected with a precision of 0.3 microns in general. The results of the calculation give the object co-ordinates of the sphere centre points with an overall precision of 40 microns.

4.2. The 40 mm diameter button targets[(1)]

The use of the large diameter targets is linked to the following constraints :

- to get precise image co-ordinates of the target centre the image has to cover enough pixels and its minimum diameter has to be approximately 10 pixels;
- for the measurement of large objects, the camera stations have to be a long distance from the object.

For the CMS Barrel Yoke geometrical validation, the distance between the camera position and the object varies from 6 to 10 m. After tests on the Barrel Yoke mock-up, we asked for the fabrication of specific 40 mm diameter targets, see figure 4.

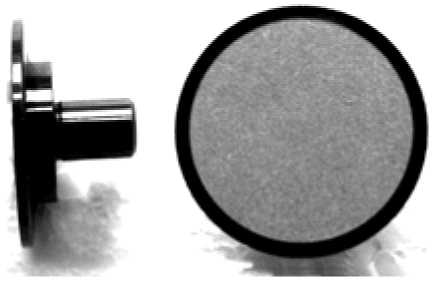

Figure 4 : 40 mm diameter button target

With a DCS 460, equipped with a 20 mm lens, the image of this type of target has a diameter of 15 pixels on a picture taken at 6 m and 9 pixels on a picture taken at 10 m.

Nearly 250 of these targets have been successfully used for the geometrical validation of the first Barrel Yoke ring in the factory.

4.3. Extended codes on magnetic plates[(2)]

To automatically name the point and quicken the calculation steps, coded targets are used. Two type of ring codes are recognised by the image analysis module of the CDW programme. The first type gives the possibility to code points from 1 to 147. The second one, called extended code type, permits naming points from 1 to 512.

In order to combine the use of button targets placed in the object reference holes, such as the 40 mm button targets, and the facility offered by the code, some plates with a central hole and a code ring stuck around have been made. During the measurement these plates are placed on the object around the target and the button target becomes a coded target.

This concept was applied to the large 40 mm diameter button targets. CERN specified plates with extended codes, made of a magnetic foil, see figure 5.

Figure 5 : codes on magnetic plates for 40 mm diameter button target

These coded plates are regularly used for the Barrel Yoke measurements to equip the reference point targets and the points of the scale bars.

4.4. Synchronisation module[(3)]

CERN has acquired a module to synchronise up to five DCS460 cameras, see figure 6. It allows the taking of simultaneous pictures of an object from cameras placed in fixed positions i.e. cameras placed on tripods.

Figure 6 : synchronisation module

Photogrammetry in this synchronised configuration is mainly used for deformation control. It can also be used for kinematics under certain conditions.

The precision of synchronisation of this type of module is only of a few milliseconds, so the data acquisition has to be done when the object is not moving or moving slowly, a speed of 10 mm/s gives a movement of 0.1 mm in 10 ms.

A process of deformation measurement in synchronisation mode is described below :

1. measurement of the object and extra points with 1 camera using the standard close range photogrammetry method;
2. no deformation applied to the object;
3. measurement of the same object and extra points with the n synchronised cameras in fixed position;
4. deformation applied to the object
5. measurement of the object points and extra points with the n synchronised cameras in fixed position;
6. repeat 4 and 5 for each deformation step.

Point 3 measurement allows the calculation of the external orientations of the cameras.

Point 5 measurement gives the new co-ordinates of the object points by intersection calculation assuming that the external orientation of the cameras does not change.

Remark : if a sufficient number of stable extra points exists with a relevant location the external orientations of the cameras can be calculated for each deformation step.

Example of deformation control using the above process, see figure 7 :

- object size 1.5 m diameter;
- 3 DCS460 cameras equipped with 24 mm focal length lenses;
- cameras placed on tripods at 2.5 m from the object;
- deformations measured with a precision (1 sigma) of 50 microns.

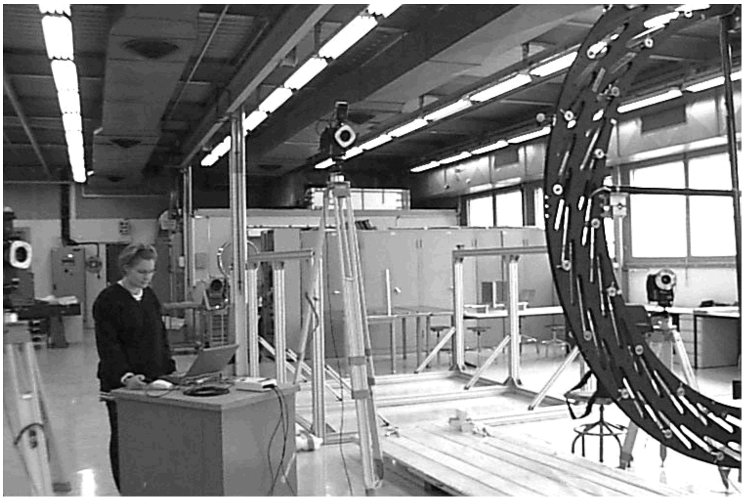

Figure 7 : deformation control using synchronisation module

5. CONCLUSION

Our three years experience proved that, when used under proper conditions, digital photogrammetry is a very precise and fast survey tool even for very large model measurements. Easy to carry, easy to handle, it allows us to work with a small team of experienced people in the field and fits to most of the environmental measurement constraints imposed by the new LHC project.

Digital photogrammetry, combined with traditional survey methods, has turned out to be a major new tool in our toolbox which is now being used in the control of construction of the first components of the LHC experiments.

(1) spherical targets, 40 mm diameter targets, are made to CERN specifications by the GMS company.
(2) codes on magnetic foil are made to CERN specifications by the AICON company.
(3) the synchronisation module is a product of the GMS company.

References

[1] **Clarisse WANTZ:** Analyse des performances du logiciel de photogrammétrie numérique Rolleimetric/CDW et son application aux installations du CERN, Ecole Nationale Supérieure des Arts et Industries de Strasbourg, France, 1998.

[2] **Jean-Christophe GAYDE EST/SU:** CMS Laboratoire ISR - Banc test alignement « minimal barrel » - Mesures du réseau, CERN, Switzerland, 1998