A Simple Iterative Alignment Method Using Gradient Descending Minimum Search

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Large tracking systems of present experiments in high energy physics consist of typically 10^4 individual detector elements. The alignment procedure has to fix up to 10^5 parameters. We propose a simple and robust iterative updating alignment method using reconstructed tracks. The geometrical parameters are adjusted using a gradient descending minimum search which does not require handling of large matrices and can be used online. Tracks with a common vertex like V^0s can be used for an efficient alignment of modules which are not linked by single tracks. The method has been successfully applied in the alignment of the HERA-B tracking system.

1. INTRODUCTION

Modern experiments in particle physics are equipped with tracking detectors covering typically volumes of $(10\ m)^3$ and 10^7 channels in typically 10^4 mechanically independent modules. The resolution of the measurements is of order μm and requires the precise adjustment with particle tracks of the 10^5 free parameters corresponding to the degrees of freedom of the modules. Blobel et al. have developed a least square fitting procedure [1] which estimate all parameters at the same time. The corresponding program package has very successfully been applied to the tracking system of H1 and the vertex detector of HERA-B.

In this paper we present an alternative approach which is based on gradient descending minimum search. It offers the following advantages:

- It is very simple, robust and fast and does not require handling of large matrices.
- It is applicable not only to single tracks but also to complex event structures. Magnet parameters can be included in the adjustment.
- It is updating and can be used on-line.

The method has been applied successfully to the alignment of the Inner Tracker of HERA-B.

2. GENERAL REMARKS

The alignment of detectors is based on the residuals, the differences between fitted and measured coordinates. Thus a crude alignment of the detectors is necessary before an automatized alignment procedure can start. The alignment of the whole tracking system in a single program is more efficient than a two-step procedure where subdetectors are aligned first.

Usually, single tracks are used to align the detector elements. These tracks connect mainly certain groups of detectors which are located near a radial line drawn from the interaction point. Thus residual plots are usually swamped by those tracks and may look perfect except for some outliers but hide a rather bad alignment of laterally located detectors. However, it is the alignment of laterally located detectors which is important for a good mass resolution. For the alignment of these detectors some detector overlap is very helpful. Even better is to use events consisting of at least two tracks with some kinematical constraint like a common vertex at the interaction point or $K^0 \to \pi^+\pi^-$ and $\Lambda \to p\pi^-$ decays to correlate detectors not traversed by the same particle. Using these events also helps to adjust overall scaling parameters (scaling, sharing, stretching of the complete detector) which are not accessible with single track fitting. In experiments with a spectrometer magnet it is sometimes difficult to disentangle magnet parameters (position and field) and geometrical detector constants. It is easy to include magnet constants in the gradient descending alignment procedure.

Contrary to what is frequently claimed, alignment usually does not require high statistics. The order of thousand tracks per individual detector should be sufficient if there is enough overlap between adjacent detectors.

3. OUTLINE OF THE METHOD

We assume that event or track parameters are adjusted by a χ^2 fit to the measured coordinates u_i of the individual detectors. The value of χ^2 depends on the difference $u_i - u_i^f$ of measured and fitted coordinates and on the position parameters of the detectors. The position parameter λ_k of detector k is modified in proportion to the derivative of χ^2 with respect to the parameter.

$$\delta\lambda_k = -\alpha_k \frac{\partial \chi^2}{\partial \lambda_k} = -\alpha_k \sum_i \frac{\partial}{\partial \lambda_k} \frac{(u_i - u_i^f)^2}{\Delta u_i^2}$$

Here α_k is a learning constant and Δu_i^2 the quadratic uncertainty used in the χ^2 calculation. The corre-

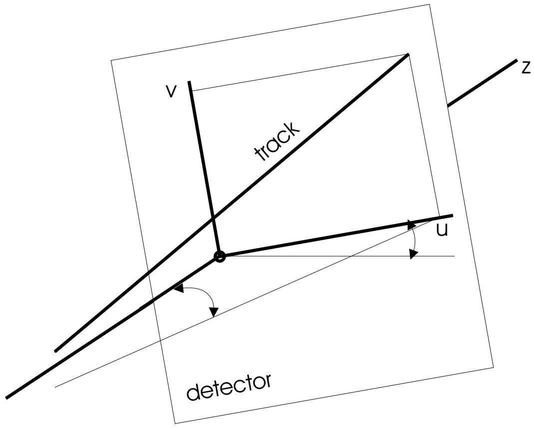

Figure 1: Coordinate definitions for a planar detector measuring the u coordinate.

sponding parameter shifts are

$$\delta\lambda_k = -2\alpha_k \sum_i \frac{u_i - u_i^f}{\Delta u_i^2} \frac{\partial(u_i - u_i^f)}{\partial\lambda_k}$$

where i runs over all measured coordinates.

An exact analytic expression for the derivative $\partial(u_i - u_i^f)/\partial\lambda_k$ can be given only in the simplest cases. There are two ways to compute it: i) It can be obtained directly from the fitting program from the observed change of χ^2 by repeating the fit with a small change $\delta\lambda_k$ of the parameter. ii) An analytic approximation is used.

The computation of a huge number of gradient components by program may require excessive computing time. The second method needs less computing power and is usually preferable.

It should be remarked that the gradient descending minimum search is insensitive to approximations as long as the steps proceed downwards in the χ^2 field. Since $u_i - u_i^f$ depends mostly on the geometrical parameters of the detector measuring u_i, all other derivatives can be neglected and $\partial(u_i - u_i^f)$ can be approximated by ∂u_i. From the six possible parameters of a planar detector usually only three are relevant. For a fixed target experiment (see Fig. 1) with one dimensional readout these are the position λ_u along the readout coordinate u, the azimuthal rotation angle λ_ϕ around the radius vector from the nominal interaction point to the chamber and the distance λ_z to the interaction point.

The three corresponding coefficients are simply:

$$\frac{\partial u}{\partial\lambda_u} = 1; \quad \frac{\partial u}{\partial\lambda_z} = \tan\gamma; \quad \frac{\partial u}{\partial\lambda_\phi} = -v$$

with $\tan\gamma$ the slope of the track in the $u - z$ plane (z is perpendicular to the nominal detector plane), and v the coordinate perpendicular to u measured in a coordinate system with the origin at $(0, 0)$ and the ϕ rotation around the z axis. If needed, the two other rotation parameters can easily be included in an analogous way.

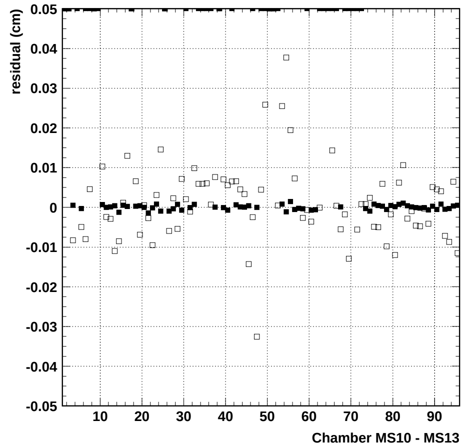

Figure 2: Mean residuals before (open sympols) and after the alignment (filled symbols). (The symbols at 0.5 cm correspond to missing detectors.)

Some remarks:

- Gradient descending minimum search often suffers from slow convergence and local minima. In our case, there are no local minima and due to the quadratic dependence of χ^2 on the difference, the χ^2 field is parabolic even far from the minimum.
- The learning constants have to be chosen such that the different parameter shifts are reasonable. The shift per event should be a small fraction of the corresponding resolution. The learning constant can be reduced during the alignment procedure.
- To minimize the computing time needed for updating data banks, the displacements of many events can be accumulated before updating.
- The same events can be used several times.
- Magnet constants can be handled in the same way as geometric parameters. The χ^2 dependence has to be estimated or computed by the reconstruction program. The additional computing time should be tolerable.

We have used the proposed method to align the Inner Tracker of the experiment HERA-B at Desy. It consists of 160 MSGC detectors. The same event sample of 10,000 events was used several times. The parameters converged after about 5 to 10 iterations. Fig. 2 shows the mean values of the residuals of part of the detectors before and after the alignment.

Acknowledgments

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References

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