Nuclear Instruments and Methods in Physics Research A 332 (1993) 284–287
North-Holland

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

A new method for fast track recognition at present and future colliders

T. Altherr [1]
Theory Division, CERN, CH-1211 Geneva 23, Switzerland

R. Vilela Mendes
G.T.A E., Av. Gama Pinto, 2, 1699 Lisboa Codex, Portugal

J. Seixas
Departamento de Física, IST, Av. Rovisco Pais, 1096 Lisboa Codex, Portugal

Received 23 February 1993

Using a very simple cellular automated algorithm we show how to recognize a large number of spirals in a given pattern. The algorithm can (and in practical application should) be implemented as a massively parallel architecture, the connections between the units being non-adaptable. We present several example of recognition of simulated particle tracks ranging from a few to one hundred.

1. Introduction

The new generation of experiments in high energy physics will have to deal with an unrivalled wealth of information, which has to be treated in an extremelly small amount of time (e.g., 15 ns for the LHC). This means that data analysis and track recognition will be a quite complicated problem in the LHC and SSC both for on-line and off-line analysis. Massive parallelism is thus compulsory and neural-like algorithms seem a good choice in this context [1].

Most of the papers adopting this last type of algorithms tend to follow an approach in which the connections between the units defining the neural architecture are adaptable. This approach is, strictly speaking, only necessary when very little is known about the function relating the data set we want to analyse to the features we want to detect in it. If we know from the start that certain characteristics are always present, we can eliminate all (or almost all) adaptability in the network and define an architecture that represents the desired input/output mapping. This is, of course, of primordial interest when one seeks to implement the feature detector in hardware, in the simplest possible way.

In this paper we present an algorithm that uses the spot reduction technique developed for particle recognition in e.m. calorimeters [2] and Cherenkov detectors (RICH) [3]. As will be clear from what follows, the algorithm works remarkably well, considering its simplicity, and opens the possibility of track reconstruction even at the on-line level.

[1] On leave of absence from L.A.P.P., BP110, F-74941 Annecy-le-Vieux Cedex, France.

2. The method of spiral reconstruction

Most of the detectors proposed for the LHC and SSC use a strong magnetic field applied parallel to the detector axis. This means that the particles will follow spiral trajectories in the detector, with pitch angle and diameter depending on the momentum (and, of course, on the magnitude of applied magnetic field, which we assume to be uniform). To reconstruct a spiral one needs the coordinates of four points at most. In our case, however, less than four points are needed, since we will assume a point on the spiral to be fixed, i.e. the interaction point, and the spiral axis to be along the magnetic field. Of course it might happen that a particle travels some time before it decays (a B meson, for

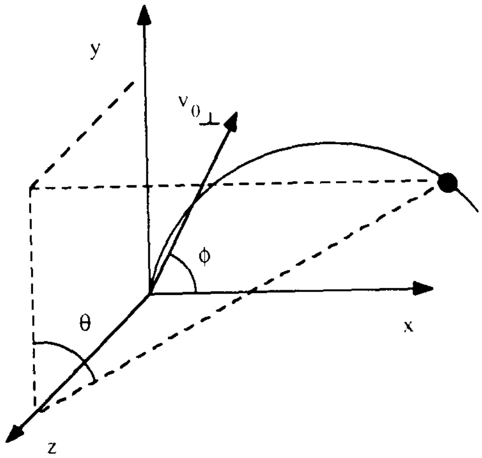

Fig. 1. Definition of the sets of variables used for the track-reconstruction algorithm.

instance, may travel a few millimetres) but we will assume in this paper that all spirals stem from a single point. This implies that, as it stands, the algorithm we have constructed is a preprocessing step for the data. The more sophisticated approach of treating spirals with different origins is a bit more intricate and will be dealt with in a different paper.

Since we know the spiral axis we only need two points to determine all the spiral parameters. We thus have the following set of equations for the spiral

$$x = \frac{v_{0\perp}}{\omega}(\cos\phi - \cos(\omega t + \phi)),$$
$$y = \frac{v_{0\perp}}{\omega}(\sin(\omega t + \phi) - \sin\phi), \tag{1}$$
$$z = v_{0_z} t,$$

where v_0 is the initial speed of the particle and $\omega = qB/E$ is the cyclotron frequency for a particle of charge q and energy E in a magnetic field of strength B. In terms of the coordinates of two points on a given spiral (we use cylindrical coordinates, see fig. 1), we have the following set of equations:

$$\frac{v_{0_z}}{\omega} = b = \frac{z - z'}{2(\theta - \theta')},$$
$$\psi = -\phi = \frac{1}{2}\left(-\frac{z + z'}{2b} + \theta + \theta'\right),$$
$$\frac{v_{0\perp}}{\omega} = a = \frac{r}{2\sin(\theta - \psi)}, \tag{2}$$
$$a' = \frac{r'}{2\sin(\theta' - \psi)}.$$

In the case considered here, we assume that all spirals have the same origin and therefore for two points (r, θ, z) and (r', θ', z') we must have $a = a'$ as a consistency condition. However, if it is assumed that the origin of the spirals has a random position on the beam axis (and this will be the case in the LHC, a problem that will have to be dealt with to solve pile-up events [4]) we can use the a and a' equations to determine this position. We will not pursue this approach here, since we only want to present the method, but this will be done in a forthcoming publication.

For every pair of hits in the detector we have a point in the three-dimensional parameter space (a, b, ψ). From the pairs that belong to the same spiral we reconstruct a cluster of neighbouring points in parameter space. Of course we also have combinations of hits taken from different spirals, but the corresponding points in parameter space do not accumulate in a cluster, they rather yield a diffuse cloud. Notice that it is neither necessary nor advisable to take all possible pairs of points in the data set in order to reconstruct the spirals. This would lead to a waste of computer-time because of the huge combinatorics. Thus, we only consider neighbouring points, which yields essentially the same information, with the further advantage of reducing the background noise in the parameter space.

Applying the spot-reduction technique described in ref. [2] to the parameter space (a, b, ψ) we then eliminate the isolated points and, at the same time, find the centre of gravity of the clusters. As usual, the spot reduction algorithm has two separate phases: first we make two or three partial weight transfers and then two or three total weight transfers. In this way we single out with good precision the centre of each individual cluster.

A comment is in order regarding precision. In the present version, to apply the spot-reduction technique, we fully discretize the parameter space and recover the spiral parameters from this discretized space. This means that the precision with which we find the location and pitch angle of a given spiral depends on the granularity of the discretization. The granularity is, in our case, strongly limited by the amount of memory available. In fact, the granularity of the parameter space depends only on the precision with which we want to separate two close-by spirals. Indeed, following the approach used in ref. [3], it is possible to discretize, for instance only two of the parameters and average over the remaining one. This was the approach used in ref. [3], which has shown to produce quite good results. This way, the two problems of i) recovering the spirals and ii) getting their characteristics, are disentangled.

3. Results

In fig. 2 we see the result of the algorithm when applied to a set of spirals. As can be seen, the reconstruction is remarkably successful considering the crudeness of the algorithm. In fig. 3, we show the number of successfully reconstructed tracks as a function of the particle momentum. For a 100 tracks event, the overall efficiency is about 95% and becomes very good for large momenta. On the other hand, for very small momenta the efficiency of the algorithm degrades rapidly. However, since very small momenta are probably not interesting in LHC/SSC physics, this may be a minor problem.

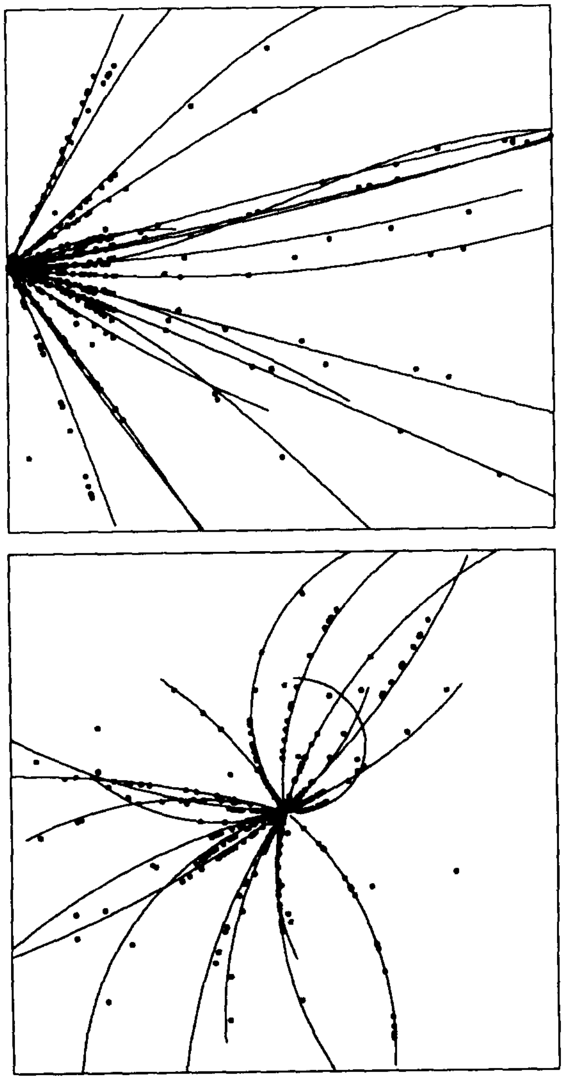

Fig. 2. A typical reconstruction example using the track-reconstruction algorithm. The upper plot represents the yz projection and the lower plot the xy projection. The dots correspond to the points used for the reconstruction and the full lines to the reconstructed spirals. We have required a minimum of ten points for each spirals in the first sector and 5% of background noise has been added.

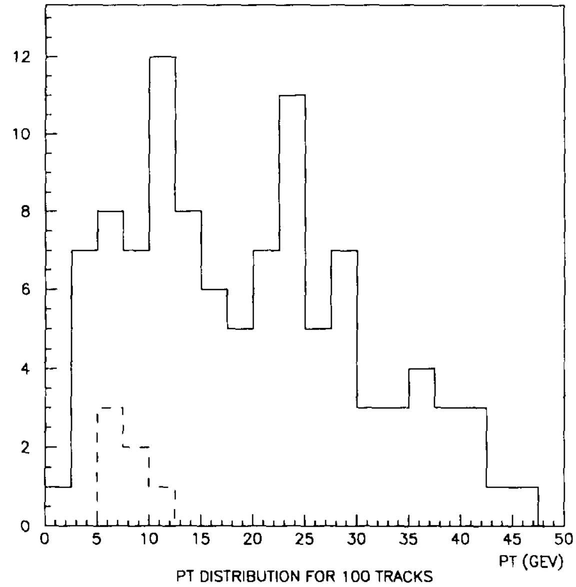

Fig. 3. Track-reconstruction efficiency as a function of transverse particle momentum. The solid histogram represents the reconstructed tracks and the dashed histogram the unrecovered or additional wrong tracks.

The time consumption of the algorithm grows like N^2, where N is the number of hits in the detector (which can be subdivided into multiple independent sectors). The execution speed in the spot-reduction algorithm is independent of N (if implemented on a parallel machine). Hence, our algorithm is in principle much faster than a conventional road-finder-type algorithm, where the computer-time consumption grows like a factorial. Also, with growing track multiplicity, the probability of failure of such algorithm increases with a consequent degradation in the reconstruction efficiency. In our case, one should only increase the number of cells into which we divide the parameter space. As shown above, this does not affect the execution speed.

It must be emphasized that the algorithm presented here is merely a first approach to a more consistent reconstruction algorithm, which embodies above all the possibility for each track to have a different origin. In this context, two things may happen: either the origin is on the beam axis, or it is not. In the latter case the situation is a bit more complicated, since we need three points instead of two to reconstruct a spiral, and the parameter space will be four-dimensional. In the former case we may keep a three dimensional parameter space, since the spiral is still defined by only two points, as we have stated previously. In any case, it will be easy to implement any one of the two generalizations in this algorithm.

Note

Copies of the program can be obtained from ALTHERR@CERNVM (FORTRAN version) or from SEIXAS@CERNVM (C + + version with graphics interface for IBM-compatible PC).

Acknowledgements

This work has been supported in part by a joint INIC (Portugal)/CNRS (France) programme.

References

[1] J.R. Hansen, in: New Computing Techniques in Physics Research, ed. D. Perret-Gallix, (World Scientific, Singapore, 1992):
S. Hellman et al., Proc. ECFA Large Hadron Collider Workshop, Aachen, 1990.
[2] T. Altherr and J. Seixas, in: New Computing Techniques in Physics Research, CNRS (1990).
[3] T. Altherr and J. Seixas, Nucl. Instr. and Meth. A317 (1992) 335.
[4] G. Tonelli, same Proc. as in ref. [1].