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IDENTIFICATION OF DIGITIZED PARTICLE TRAJECTORIES

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IDENTIFICATION OF DIGITIZED PARTICLE TRAJECTORIES

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High-energy Physics Laboratories make increasing use of particle detectors which directly produce digital measurements of trajectories at very high rates. Data collected in vast amounts during experiments are then analysed by computer programs whose first task is the recognition of tracks and reconstruction of the interesting events. This paper discusses the applicability of various Pattern Recognition approaches. Examples are given of the problems and the practical achievements in this field.

1. INTRODUCTION

In high energy nuclear physics, interactions between elementary particles are studied at energies achieved by particle accelerators. These energies are high enough to allow the production of new particles. Each interaction - or event - is investigated by observing the trajectories of the incoming and the outgoing particles. These observations may be photographs of bubbles in bubble chambers or signals given by electronic detector devices localizing the particle trajectories. There have been many papers devoted to the problems of Pattern Recognition in Bubble Chamber pictures: see Ferran [1], Brown [2], White [3]. The patterns encountered in the physics done with electronic detectors and the recognition approaches adopted, form the subject of this paper.

In recent years, developments in the electronic detection and information recording mechanisms have led to new types of devices capable of producing direct digital measurements of charged particles trajectories at very high rates. The wire chamber (see Quercigh [4]), the multi-wire proportional chamber (Charpak [5]), and the spark chamber with TV-camera read-out (Gelernter [6]) are examples of widely -used filmless detectors. Depending on the packing density of the detectors, the number of measured co-ordinates per trajectory will vary from very few to several hundreds. Thus, an event is normally represented by some 10^2 to 10^3 digitizings, each digitizing being encoded typically in a 12-16 bit string. An electronic experiment may involve the analysis of 10^5 to 10^7 events, thus implying the fully automatic processing of the data. The first stage of the analysis is the classification of the digitized events. This classification can be performed only when physical and geometrical properties of the particles and their tracks are known. In order to extract these properties, the particle tracks have to be found. This means selecting amongst the available digitizings, those belonging to

each particle trajectory. Once the trajectories are identified, the events are reconstructed and classified by a chain of programs finally leading to the physical results.

2. RECORDING DEVICES

Similarly to a flying spot digitizer, a TV camera read-out delivers digitizings representing points in a two-dimensional projection of the event.

A wire chamber consists normally of several parallel wire planes separated by a few centimeters. Each wire plane contains many parallel wires at spacings of a few millimeters typically. When a particle has passed near a wire, a digitizing is recorded by the electronic read-out, indicating the wire and the plane numbers. Thus, from the known positions of the wire in the plane, and of the plane in the detector, a point in a two-dimensional projection is obtained. Different projections result from different wire orientations.

3. TRACK FINDING

We shall assume that the digitizings have been submitted to all necessary preprocessing, e.g. calibration, correction for distortions, normalization, so that they can simply be regarded as points in convenient two-dimensional projections. The recognition of trajectories is then performed in two steps:

i) selection of a combination of digitizings likely to belong to one trajectory, and ii) test of the validity of this assumption. The "brute force" approach consisting of testing all possible combinations of digitizings for such properties is almost always forbidden by the excessive amount of computer time this would require. Therefore, a first task of the track finding procedure is to minimize the number of combinations which have to be tested. The other important task is the selection of efficient decision criteria for these tests.

Because of the wide variety of detector arrangements and patterns to be recognised, so far no universal track identification method has been found. Some progress, however, has been achieved in developing methods able to cope with different types of events in the same detector device, thus detaching somewhat the pattern recognition problem from the specific experiments. In the following, to give an idea of the problems we shall outline three different recognition techniques developed at CERN.

4. THE OMEGA DETECTOR

Fig. 1 represents one of the two stereoscopic projections of a nuclear reaction observed inside the Omega spectrometer. An incoming beam of particles interacts in the target giving rise to charged products the trajectories of which are photographed by two stereoscopic sets of four television cameras each. To allow for a 4π detection the target is surrounded by a spark chamber of 80 gaps in the forward direction and two smaller chambers of 32 gaps each on the sides; all these chambers are placed in an homogeneous magnetic field so that the shape of the trajectories may be approximated by a helix. In addition, a few multiwire proportional chambers outside and inside the magnet allow the detection of either the incoming beam or some specific particle respectively. Due to the large amount of data, the smoothness of the curvilinear projections and a fairly uniform density of points along the trajectories, the track finding is based on a combination of two-dimensional and three-dimensional track following methods. Most of the particles traverse only the forward chamber and thus their trajectories are defined by a simple section of track. Some other ones are defined in the same way in the side chambers by a unique segment. A more complex category consists of the particles traversing one of the side chambers and the forward chamber too; as a consequence their trajectories are defined by two collections of points which have to be connected. Three cases are then possible: 1) one knows how to identify independently both collections which will be connected later on. 2) one of the two collections does not contain enough points to be identified; in this case each of these points will be used as single items to complete the other collection. 3) both collections do not individually contain enough points; they have to be treated globally. Thus the track finding consists of the following operations: i) 2D track following, ii) track matching between the projections, iii) track element connection, iv) track extension by 3D track following, v) global search for tracks on the residual points.

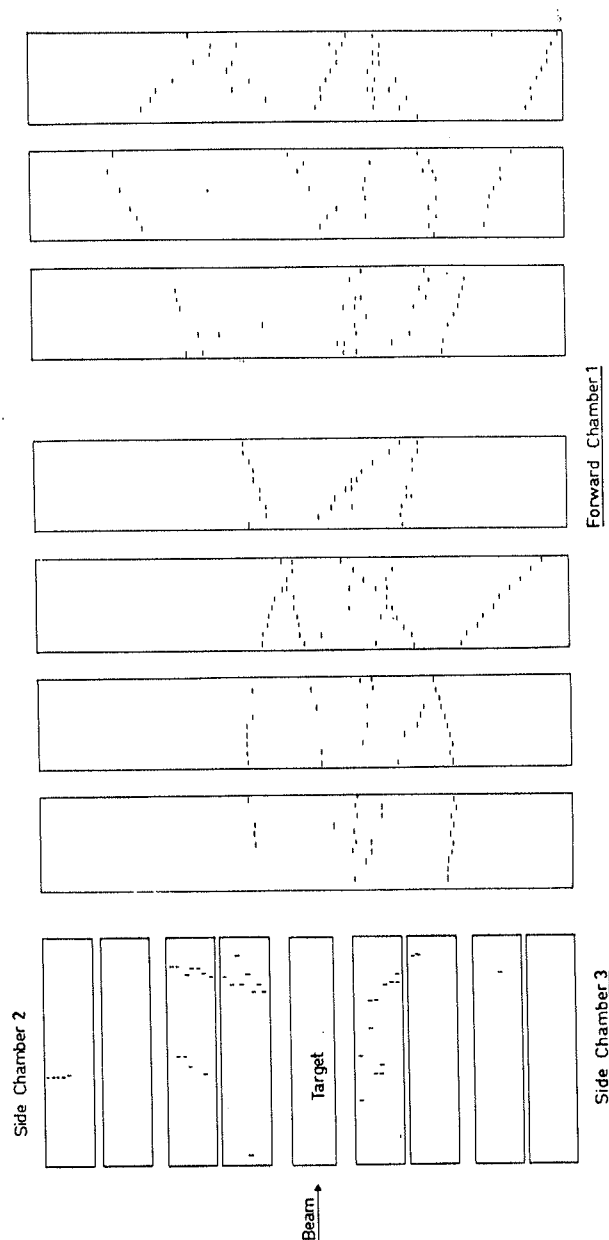


Fig. 1 : Omega spectrometer event

4.1 TRACK FOLLOWING PRINCIPLES

The first task of the track following method (Bourgeois [7]) is to find combinations of three points in at most five consecutive gaps to take account of the detector inefficiencies. The tracks defined by these combinations supposed to represent the start of trajectories are then extrapolated into the following gap. In this gap a new point is added to the original track if it conforms to the prediction within a calculated error limit. This process is continued until it is not possible to assign new points. The curves used to extrapolate are either parabolae or circles, the former being fast to evaluate, the latter more accurate.

4.2 TWO DIMENSIONAL TRACK FOLLOWING

A 2D track following process is firstly applied to the side chambers. This allows in case of success to compute an approximation of the vertex from which the tracks are radiating. This vertex is computed as the average of the intersection points of the incoming beam (detected by the wire chambers) with the side tracks. The track following is then performed in the forward chambers starting from the far end, which is much less confused than the target region. The vertex position as previously defined is only used in the neighbourhood of the target to help finding wide angle tracks which have escaped partially or fully to the side chambers detection.

4.3 TRACK MATCHING

Each space track being defined by its two projections, this operation consists of associating the track images in the two views with each other in order to find the pairs defining space tracks. A matrix of track correlating values is computed using simple functions such as sign of curvature, length, missing points in coincidence and simple spatial reconstruction. An assignment algorithm reported by Bourgeois [8] allows to compute the best correlation solution. The following operations are then performed in space allowing to combine the three different geometrical systems into a unique cartesian system.

4.4 TRACK ELEMENT CONNECTION

For each pair of track elements as represented in fig. 2, one defines a plane P allowing to compute the intersection points A and B of the two tracks and their directions at these points. If these quantities agree within certain error limits, a fit is performed on the points of the two segments together to compute a global RMS deviation. If this deviation conforms with an experimental threshold the track elements are connected. If not, they are considered in the next step.

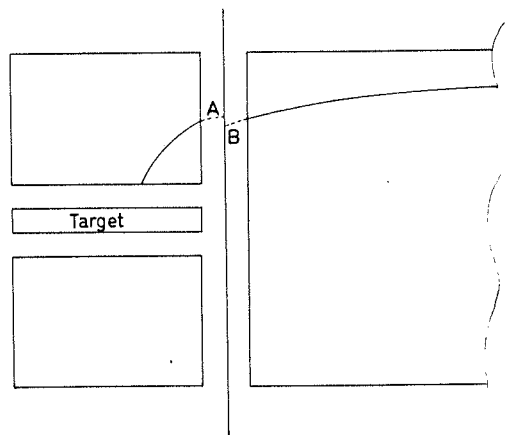


Fig. 2: Track element connection

4.5 EXTENSION BY THREE DIMENSIONAL TRACK FOLLOWING

All the tracks not coming from the front of the target or not connected as previously described, are considered for a possible extension. Tracks coming from chamber 1 are extrapolated in space up to the target in chambers 2 or 3. In the same way the tracks coming from these chambers are extrapolated in chamber 1 until they leave the volume of detection.

The points of the two projections not associated with matched tracks are combined to compute space points. These points are then assigned if they agree with the three dimensional track extrapolations. This technique is quite similar to the two-dimensional track following.

As the number of tracks one is looking for is not known, the final part of the particle identification is a precise spatial reconstruction. This allows the retention from the list of identified tracks of those emanating from the vertices.

4.6 SUMMARY OF PERFORMANCE

The performance of the program does not depend very much on the track multiplicity which is on average four or five. This is true as long as the detector is able to record efficiently multiple track events. In practice, this detector efficiency varies from 100% to 60% and the success rate of the track recognition ranges from 95% to 90%. The computer time varies approximately linearly with the number of tracks and increases when the detector inefficiency increases. A typical figure is about 60 msec. on a CDC 7600 computer to perform the analysis of a 4-prong event.

5. THE SPLIT FIELD MAGNET DETECTOR

5.1 EXPERIMENTAL LAY-OUT

In the intersecting storage rings at CERN, two

high energy proton beams collide at eight intersection points (fig.3).

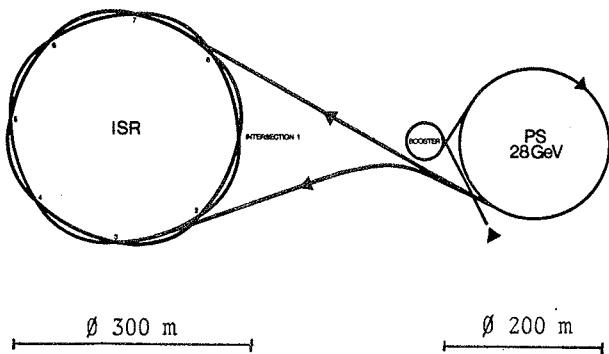


Fig.3: Intersecting storage rings at CERN

The head-on collision of protons at this energy leads to the creation of many new particles, emerging into all directions in space. In order to detect them in the full solid angle, the split field magnet detector has been developed. A schematic view is given in fig.4.

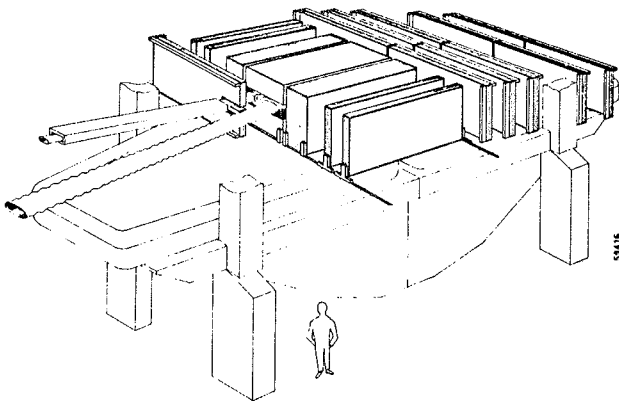


Fig. 4: SFM detector

The detector consists of 36 wire chambers, surrounding the interaction region completely. Due to the strong magnetic field the trajectories of the charged particles are bent thus allowing their momenta to be measured. In fig. 5 the top view of a typical event is given (the number of charged particles per event varies between two and about thirty). The crosses in the figure indicate the coordinates as given by the wire planes. They are connected along the actual particle trajectories. Without these connections, it is very difficult, if not impossible, to detect these trajectories visually, in contrast to those in bubble chamber photographs. The problem here consists in finding tracks with at least three coordinates in each of two projections, thus leaving very little

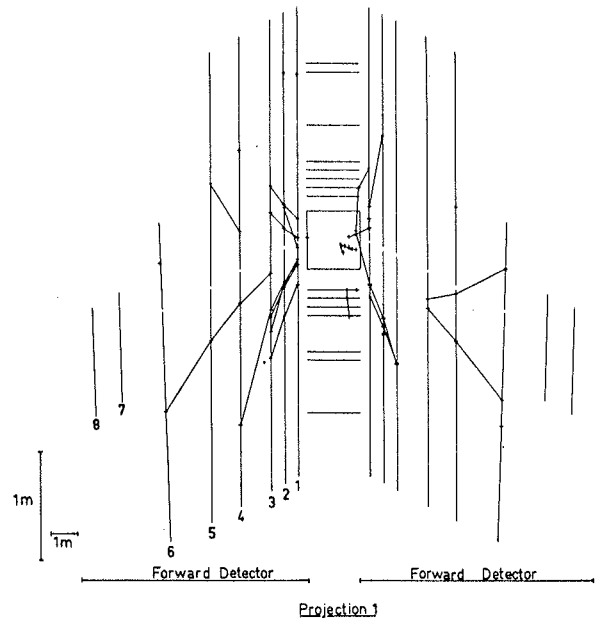


Fig. 5: Event in SFM detector

redundancy for testing these tracks.

5.2 TRACK FINDING

Here we shall consider the track finding in the so-called forward detector only, as indicated in fig.5. The track finding is performed in three steps: i) pre-processing, yielding space points, ii) selection of track candidates in chamber subsets, iii) selection of final tracks from the track candidates by applying a consistency condition. In each step, extensive use is made of the a priori knowledge of the event topology and of the physical nature of the particles.

5.3 PRE-PROCESSING

In each chamber in the forward detector some wires deliver two orthogonal coordinates per particle traversing the chamber. In the general case of more than one particle passing through the chamber, the coordinates in the two projections have to be associated into pairs, each of which gives the coordinates of a particle impact point. This association is done with the help of additional information delivered by the digitizings from wide inclined strips (5cm wide, the wire spacings being 2mm). The association of coordinates into space points is normally not free from ambiguities, so that a certain number of wrong space points are added to the correct ones. The number of these additional wrong combinations is minimized by applying Munkres' algorithm (Bourgeois [8]).

5.4 TRACK CANDIDATE SELECTION

As may be seen from fig.5, hardly any particles

intersect all the chambers of a forward telescope. It is therefore convenient to sub-divide the forward detector into sub-sets of chambers, each sub-set containing possibly all space points of one or several trajectories. The selection of such sub-sets is performed in two steps: In the first, the forward detector is split into two overlapping regions, being region I = chambers 1-6, region II = chambers 4-8, (see fig.5). For geometrical reasons, particles will normally give digitizings only in part I or in part II, but only very rarely in both parts. Furtheron, due to physical reasons, part I will contain the bulk of the tracks. These tracks correspond to particles of rather low momenta and are therefore strongly bent in the magnetic field. Part II, however, will contain space points from particles of high momenta. Their trajectories change sign of curvature at chamber six, as the magnetic field is of opposite direction in the two halves of part II. Both parts are treated identically but separately. Due to the reasons mentioned above, a trajectory in part I can be approximated by parabolae in the two orthogonal projections, whereas in part II a straight line in one projection, and a second order spline curve in the other projection are used. In each part, chamber sub-sets are chosen fulfilling the two requirements that tracks with many space points are found first, because they are better defined due to their higher redundancy, and that tracks are found first in the chambers far from the intersection region, because there the tracks are better separated in space. For these two reasons, therefore, in part II for example the following sub-sets of chambers are treated consecutively: 4-8, 5-8, 4-7, 6-8, 5-7, 4-6. In each sub-set tracks are looked for in the following way: a track is initialized by a combination of three space points, one in the first, one in the central, and one in the last chamber of the sub-set. These three points define the approximate curve mentioned before. The extrapolation of this curve must pass sufficiently near to the interaction region, and the maximum curvature of the curve must remain below a certain value. This second condition for an initial track reflects the effect of the magnetic field, which prevents particles of too low momentum from penetrating into the forward detector.

If the sub-set consists of three chambers only, each such initial track is accepted as track candidate. In the case of more than three chambers, additional points must be found inside a road around the approximate curve, and finally a cut is applied based on the mean square error of a fit to all points on a track.

5.5 CONSISTENCY CHECK

The way in which a track candidate is defined suffers mainly from two facts: the low redundancy, and the only approximate knowledge of the actual

curve form. It is therefore not surprising that the procedure described so far will, in the case of events with high multiplicity, yield not only the real tracks, but as well a great number of track candidates which are actually wrong associations of space points. In order to reduce the number of these wrong combinations, which may be a factor twenty or more higher than the number of the real tracks, the concept of the consistency of the solution was introduced. This is based on the assumption that no two particles can give the same digitizings anywhere in a wire plane (the probability that this may happen is less than one percent for track pairs). According to this assumption, the track candidates found in one chamber sub-set are cross-checked for their compatibility. This can be represented in the form of a graph (fig.6a), where circles represent tracks.

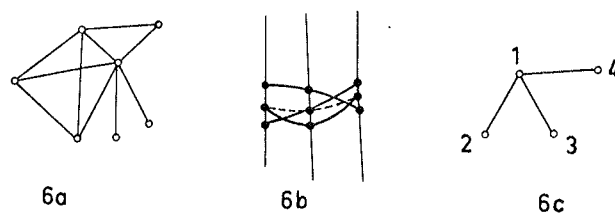


Fig. 6: Graph representation of tracks

Incompatible tracks, i.e. tracks with at least one digitizing in common, are connected. It can now be argued, that the real tracks are the maximum set of independent elements in this graph, that is the maximum number of elements being all compatible with each other. This can be illustrated by fig. 6b. In fig. 6b, four tracks are found in a sub-set of three chambers, the solid lines indicating the correct ones. This results in the graph 6c. Following the assumption that two tracks cannot have coordinates in common, one can either accept track 1, or tracks 2,3, and 4. Obviously, the second solution is to be preferred. It is possible to find all maximum independent sets of a graph even in the general case (Das [9]). This method, however, cannot be applied rigorously and has been modified in the program described here. This is mainly due to two reasons. Firstly, there exists normally a great amount of background points, mainly from particles giving too few digitizings to be detectable, or from particles generated in interactions not taking place at the intersection region of the proton beams. This weakens considerably the argument for the maximum independent set being the correct solution. Secondly, there exist very often equivalent solutions of the maximum type. Accepting all equivalent solutions of such graphs would very often result in no reduction at all. Therefore, on the level of inconsistent pairs, a probability for each track is introduced, based on the quality of the fit mentioned before. This probability then decides whether one of the two

tracks can be rejected, or whether both have to be kept. This modification of the rigorous method cannot always provide solutions which are completely compatible, but it still reduces the amount of wrong tracks by a factor of up to ten.

5.6 ADDITIONAL PROCEDURES

The points of an accepted track are not further used for initialization of new tracks, thus reducing considerably the number of combinations to be tested. The method described here has two main aims, apart from finding the correct tracks: to reduce the number of track candidates which have to be tested, and to reduce the number of tracks which have to be accepted. This in addition to the method described above, can be improved by applying the method twice in succession, once with narrow cuts to define good tracks with high probability, and, after having removed their points, find the rest of the tracks with the full width of the cuts necessary for this.

5.7 RESULTS

The method described above gives results depending strongly on the multiplicity of particles in an event. The track finding efficiency for tracks with at least three space points lies between 99% and 80% for multiplicities between two and seventeen charged particles. The time increases with the multiplicity to the power of 2.5. A typical event with 12 charged particles takes 150 msec to be processed on the CDC 7600.

6. THE R603 SPECTROMETER

6.1 EXPERIMENTAL LAYOUT

A sketch of the experimental apparatus is shown in figure 7.

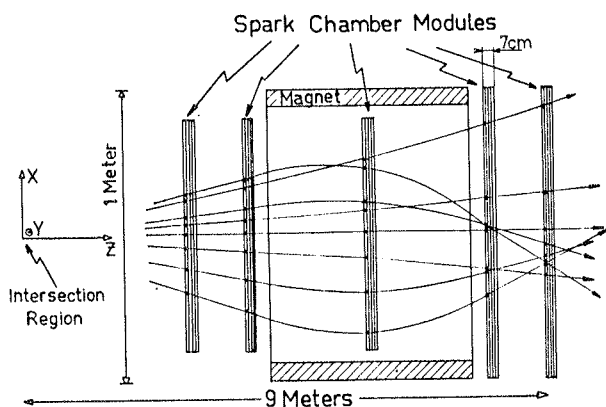


Fig. 7: Schematic view of the R603 spectrometer detector

This spectrometer is currently in operation at the CERN Intersecting Storage Rings and consists of five plane wire spark chamber modules and one magnet whose main magnetic field component is along the y axis. Some of the particles produced by proton-proton interactions taking place in the intersection region are detected by the spectrometer as they go through its various parts. Each chamber module consists of an assembly of four closely packed wire spark chamber planes, whose wires are oriented in different directions: 90° (x), 0° (y), -45° (u), 45° (v) with respect to the x-axis. Thus, the passage of a particle through one module gives rise to four digitizings representing the x, y, u, and v coordinates of the trajectory in the respective chamber planes (all parallel to the xy plane). From this information it is possible to deduce the space points $(\bar{x}, \bar{y}, \bar{z})$ belonging to the trajectory at the median plane of the module. Limiting our attention to the particles which pass through all five modules, we can represent their trajectories by five pairs of coordinates (x_i, y_i) (for $i = 1, \dots, 5$). Denoting $y_i = x_6, \dots, y_5 = x_{10}$, a track is then described by a 10-component vector $\vec{x} = (x_1, \dots, x_{10})$ and the pattern recognition problem to be solved consists then in extracting from the set of all possible $\vec{x}$ obtained from the digitizings, those which correspond to real trajectories. As will be seen in the next sections, this task can be successfully accomplished in a quasi-automatic way by using feature selection techniques.

6.2 FEATURE SELECTION

The trajectory of a charged particle in a magnetic field is governed by the Lorentz equation $\dot{\vec{r}} = \frac{A}{p} \vec{r} \times \vec{B}$ where $\vec{r}$ is a point on the trajectory, $\vec{B}$ the magnetic field at that point, A a constant, p the momentum of the particle, and the dots mean differentiation with respect to time. The general solution of this equation contains five integration constants, so that five parameters are necessary to describe completely the trajectory of the particle. Thus, the coordinates of any point on the particle path are functions of these five parameters and, conversely, five coordinates define a trajectory provided that they are independent. Therefore, with a detector measuring n coordinates per track ($n > 5$) one disposes of $n-5$ constraints equations which must hold between the n variables of each track, thus defining a five-dimensional subspace in which all tracks have to lie. The question is then whether or not it is possible to find by a suitable transformation five variables ("features") which are most relevant for the description of this subspace and to obtain, by the same transformation, $n-5$ non-significant variables. The latter, however, should provide simple and powerful tests for the classification of the n-dimensional vectors delivered by the detector. This can

indeed be achieved by using automatic feature selection techniques based on the method of principal component analysis (Karhunen-Loève expansions see Andrews [10]). These techniques have been widely used in a variety of pattern recognition problems and have been applied at CERN by Wind [11] in the momentum parametrisation of known trajectories of particles. Generally speaking, the main purpose of the techniques in this context is the selection of an optimal set of variables resulting in simple and efficient classification algorithms. As will be outlined in the next section, the procedure adopted is to learn the characteristics of the objects to be recognised on a limited number of known objects ("training" sample), and to classify the new candidates imitating these known prototypes.

6.3 EXAMPLE OF APPLICATION

As shown previously, a particle passing through the spectrometer is represented by a vector $\vec{x}$ in a 10-dimensional space. The geometrical properties of the tracks detected by the spectrometer are obtained by making a detailed study of a known sample of N tracks ($N \approx 1000$). There are many ways of choosing this learning set and, in our case, a quite satisfactory choice consisted in generating tracks originating from the intersection region with momenta and crossing points at the magnet entrance plane being both uniformly distributed over their respective allowed ranges.

Using this collection of N tracks, one defines the covariance matrix

$$A = \overline{(\vec{x} - \bar{\vec{x}})(\vec{x} - \bar{\vec{x}})^T}$$

where τ denotes transposition and bars indicate mean values over the sample, and one computes by standard methods its eigenvalues and eigenvectors. The matrix A being positive definite, it is convenient to order its non-negative eigenvalues by decreasing magnitude and to define a new orthonormal basis of the original 10-space with the set of corresponding eigenvectors $\{\vec{w}_i\}$.

Expanding the vector $\vec{x}$ into the set $\{\vec{w}_i\}$ one obtains

$$\vec{x} = \sum_{i=1}^{10} c_i \vec{w}_i$$

where $c_i = \vec{x} \cdot \vec{w}_i$ is the component of $\vec{x}$ along the

"feature" axis $\vec{w}_i$. This transformation from the pattern space to the feature space is just a rotation which has the property of minimizing the mean square error introduced when the prototypes of the sample are approximated by an expansion into the m best features corresponding to the m largest eigenvalues ($m < 10$).

The ranges of the coefficients c_i over the N -track sample are shown in table 1.

	c_1	c_2	c_3	c_4	c_5	c_6	c_7	c_8	c_9	c_{10}
without errors	900	800	300	15	13	.9	.15	.1	.03	.0002
with errors	as above					.85	.65	.8	.7	.8

TABLE 1: Range of absolute value of coefficients c_i

It is clearly seen that the coefficients $c_6, \dots, c_{10}$

are not significant for the track description but provide instead very powerful tests of the validity of the combination $\vec{x}$ supposed to represent a track. This fact remains true when measurement errors are introduced on the track coordinates. From the behaviour of these least significant variables, it is not difficult to construct reliable decision functions for the track classification. The quantity

$$d^2 = \sum_{i=6}^{10} c_i^2$$

is one such function whose value remains small for all true tracks. Its power to distinguish between correct and wrong point combinations is best illustrated in figure 8.

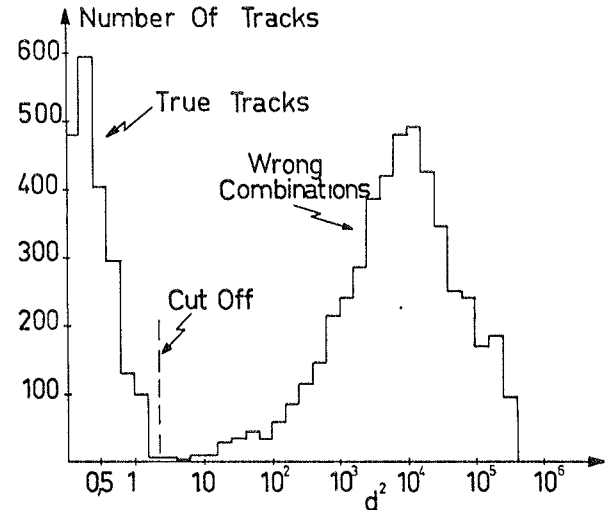


Fig. 8: d^2 for all possible point combinations

In fact, all individual coefficients c_6 to c_{10} have a similar behaviour with, however, a slightly weaker separation power for some of them.

To summarize, the procedure to follow requires the following steps:

- i) Generate a representative track sample and build up the covariance matrix A . At this stage, depending on the problem to be solved, it may be useful to introduce measurement errors on the track coordinates.
- ii) Compute eigenvalues and eigenvectors of A and perform the rotational transformation.
- iii) Study the behaviour of the various coefficients c_i for true tracks with/without simulated measurement errors.
- iv) Build up appropriate recognition tests.
- v) Use these tests to recognise valid from wrong combinations of coordinates in the analysis of real data.

6.4 RESULTS AND DISCUSSION

The application of this method of track identification has presented the following advantages:

- i) the separation power achieved is essentially of the same order of magnitude as the measurement error for one coordinate. A recognition efficiency of almost 100% was obtained for events having up to 10 tracks.
- ii) the computer implementation is simple.
- iii) the computer time required by the recognition process is rather short, provided one does some preselection, thus avoiding the "brute force" method which consists of trying all possible point combinations. This is the case for most applications and, in our given example, the preselection consisted firstly of calculating space points (x,y) in each module and, secondly, of checking that these points were roughly on a straight line in the projection parallel to the main field component. The timings achieved on a CDC 7600 computer are plotted in figure 9.

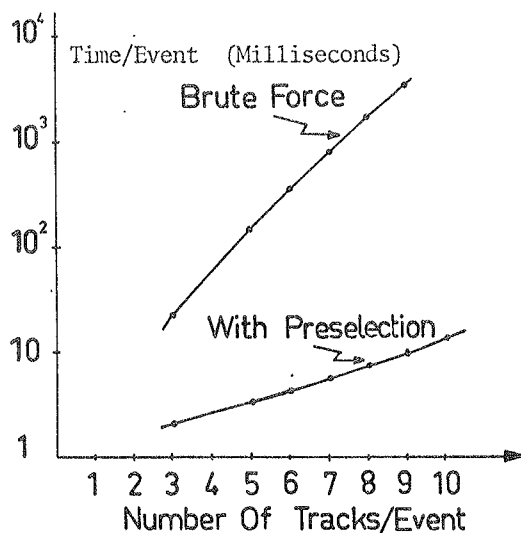


Fig. 9: Timings for the track finding program (CDC 7600)

- iv) The detector arrangement may consist of chambers placed partly or entirely inside the magnetic field.
- v) The method is applicable separately to individual projections, but the track recognition is then much more efficient for those projections where the magnetic field bends the trajectory most.

After having enumerated some of the main advantages of the method, it is worth mentioning its limitations and drawbacks, which may, in some cases, prevent its utilisation.

- i) The method has been unsuccessful for detector arrangements where the chamber planes are not parallel. In order to overcome this difficulty, one has to define new coordinates on fictive parallel planes. In practice, this results in a weaker separation power.
- ii) The vectors defining the tracks for a given detector arrangement should always be defined by the same number of components. This may not always be the case, due to chamber inefficiencies or to tracks not going through all the detector planes. In order to deal with this situation, one can use separate transformation matrices for each plane combination of interest. This may become rather inconvenient for a large number of plane configurations. In the R603 spectrometer, the arrangement of chambers in several compact modules solves the problem of local inefficiencies whereas the small number of modules allows the solution of one separate matrix per configuration.
- iii) The degree of homogeneity of the magnetic field plays a definite role in the practical applicability of the method. Although no quantitative analysis of this effect is yet available, it has been found experimentally that, in the case of a very inhomogeneous field, simple recognition criteria are very difficult to obtain.

CONCLUSIONS

The first question that comes to mind is "can the computer cope, unaided, with this track-finding job?". We have tried to answer by giving three specific examples of rather sophisticated experimental facilities, going through the technical aspects in some detail and indicating the ranges of performance achieved so far with fairly complex events. The success rates are certainly acceptable if one can guard against biases. This is normally ensured by simulating the experimental conditions very carefully beforehand and then inspecting the events rejected by the automatic system, e.g. by recovering samples with interactive displays.

The methodology is dominated by the heuristic approaches. One has developed a kit of tools which can be combined, timed and used effectively on a wide range of problems. A priori knowledge of the experiments plays a crucial role in the optimization of success rates and execution times.

Perhaps the most worrying problem today is the rapid amplification of the gap between data taking and processing times. The progress recently made in experimental technology, e.g. new accelerators and storage rings, higher intensities, new electronic detectors, on-line data acquisition systems, etc., has outweighed the advances in the corresponding data processing systems. The mismatch is now typically one to two orders of magnitude between the time it takes to record one event and the time it takes to reconstruct and classify it with the most powerful computers available.

Looking to the future, developments will proceed in three main directions. Firstly one will continue to look for faster algorithms. The dimensionality reduction approach described in our third example is particularly promising. The computer time spent with the training sample seems to be a profitable investment in experiments with very high statistics. Secondly one will investigate further the applicability of specialised hardware processors (Hansroul [12]). The potential gains in execution speed are such that a reasonable time balance might be re-established. Here the problems arise from the design of the processors as well as from their proper integration in the data handling systems. Thirdly, one will be forced to change the attitude towards the overall design of experiments. The flexibility offered by modern detector devices should be exploited to produce data patterns compatible as far as possible with the automatic recognition and reconstruction techniques available. Progress along these lines may lead to a more systematic handling of the pattern recognition tasks.

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