A SIMPLE EXAMPLE OF TRACK FINDING BY FOURIER TRANSFORM AND POSSIBILITIES FOR VECTOR OR OPTICAL PROCESSORS

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We present some simple examples of finding tracks by Fourier transform with filter or correlation function. We discuss the possibilities for using this method in more complicated real situations and also discuss the processing times which might be achieved.

The method we discuss here is only one possible method of using vector or optical processing with a Fourier transform to find tracks. We have been guided by imitating the simplest examples in the literature on optical pattern recognition and optical processing. This was motivated by the possible benefits in speed of processing in the optical Fourier transform wherein an entire picture is processed simultaneously. The speed of a computer vector processor may be competitive with present electro-optical devices.

The basis of the method is as follows: A lens near a picture which is illuminated by plane-wave, monochromatic, coherent light will produce the two-dimensional Fourier transform at the focus by means of Fraunhoffer diffraction. What we call the picture is a mapping of hits in some two dimensional projection onto a grid such as a 128 x 128 electro-optical device or an array in a program.

We note that the Fourier transform is of the amplitudes and that the observable is the intensity or amplitude squared.

In general, to do pattern recognition, one correlates the complex conjugate of the transform of the object of interest with the transform of the picture to be searched. This is typically done with holograms in film. Beautiful examples of finding buildings in cities, railroad tracks in fields, and words in books can be found in the literature.[1,2] Film is obviously not applicable in our need for millisecond time scales. If we think of the object to be searched for as simply a solid straight line, and not a pattern of dots, its transform is a purely real straight line through the origin and we can filter with fast on-off electro-optic filters or computers. High momentum tracks in real space are almost straight lines and we can map all tracks to straight lines in R vs. cos ϕ space in a two dimensional projection.

Information such as whether or not there are many hits aligned at a certain angle can be obtained from a single stage transform and filter or single lens, filter, and detector in the optical case. If we use a second stage to transform back to the original space after filtering, we get position information which was buried in the phases after only one stage.

One general problem with the Fourier approach is that we want to know the position of the line found but the Fourier transform is position independent and the filtering gives us only the angle of the line. The solution comes from the fact that when we retransform, only a few lines should remain and they will have large intensities almost everywhere along the line in the field (as shown in the lego plots). One simple approach is to do a search at right angles to the expected track or along the edge of the picture for pixels with high intensity (which should not involve more than a few times 128 comparisons,) and then do a sum along a line through the pixel at the appropriate angle to see if enough pixels are lit up to constitute a track. The method finds roads and can be applied in a 2-D projection of real space or in a plot of R vs. ϕ for hits.

For the real space case, the correlation signal with the transform is an indicator for a road with the ϕ about the interaction point corresponding to the filter chosen. Assume we use four pictures, one for each quadrant of the 2-D projection of hits in the chamber. A fine track search would require setting up about 200 filters per picture if 128 x 128 arrays were used.

For the R - ϕ space case, the correlation signal would indicate the presence of any tracks within a momentum range corresponding to the filter. No information about the position of the track would be available at that stage (since the Fourier transform is position independent) but by retransforming the filtered transform (correlation signal) we get the roads in R - ϕ space. A particularly useful method would use both applications of the transforms as follows: in R - ϕ space we use a single filtering which gives all tracks over 50 GeV/c and we use the reconstruction to give the ϕ of all such tracks. These few ϕ values can then be used in selecting filters for real space to give the roads for only high momentum tracks.

With a 128 x 128 array, the angular resolution is about plus or minus 4 mr. Assume we make a R vs. θ plot of hits in a typical tracking chamber of 1 meter radius and 1.5 tesla field. Then the momentum resolution (Δ p/p) we could get with a simple filter on the Fourier transform would be worse than 2% p and a single processing with the filter would find roads for all tracks over 50 GeV/c. Of course, an array of more pixels would give better resolution if needed.

In our example the resolution of the filter was about $\pm$ 50 mr and we found that reconstruction after filtering gave both roads for two tracks differing in angle by 50 mr.

In our example we have three tracks with hits typically five pixels apart on a 128 x 128 grid. Figure 1 is a plot of the tracks showing the square of the real initial amplitude. If these tracks came from a common vertex in real space, our example would correspond to tracks in R - ϕ space with momenta of 22.5, 3.5 and 3.6 GeV/c having slopes (ϕ/R) of .01, .6, and .65 with a 15 kG field. The 2-dimensional complex transform was done with I-128 from CERNLIB and remapped to put low frequencies in the middle like an optical transform.† Figure 2 shows the intensity from complex amplitudes after the transform. The filter was very coarse, accepting plus or minus five pixels away from a test line through the center of the trans

† Caveat Emptor: The fast Fourier transform I-128 in CERNLIB gives the low frequencies at the ends of the range and high frequencies in the middle. Furthermore, zero frequency and the highest frequency are only represented once and all other frequencies twice. The optical Fourier transform gives the lowest frequency in the middle (a wide lens focuses light to a point), and the high frequencies at the sides.

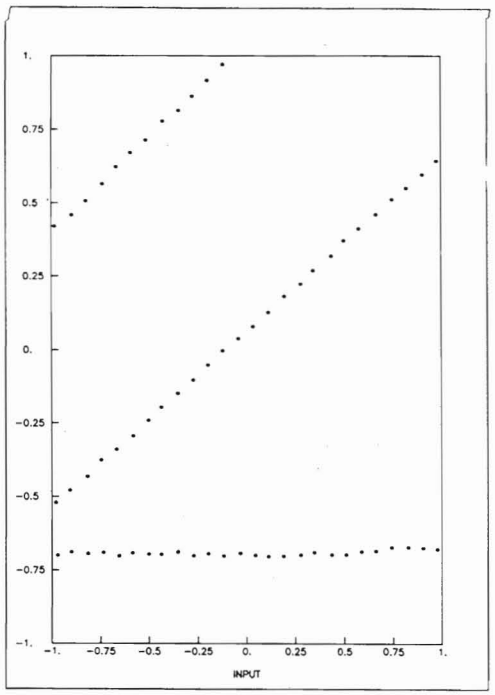

Figure 1

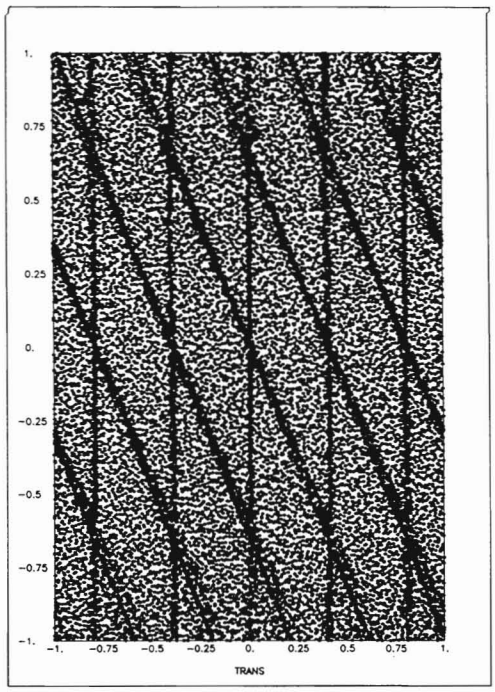

Figure 2

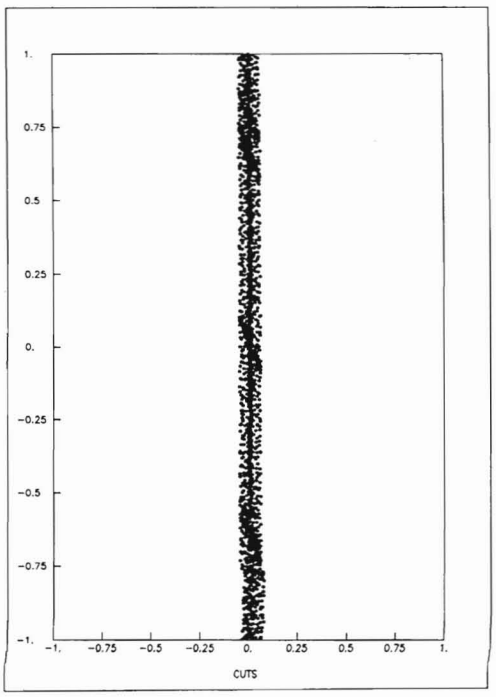

Figure 3

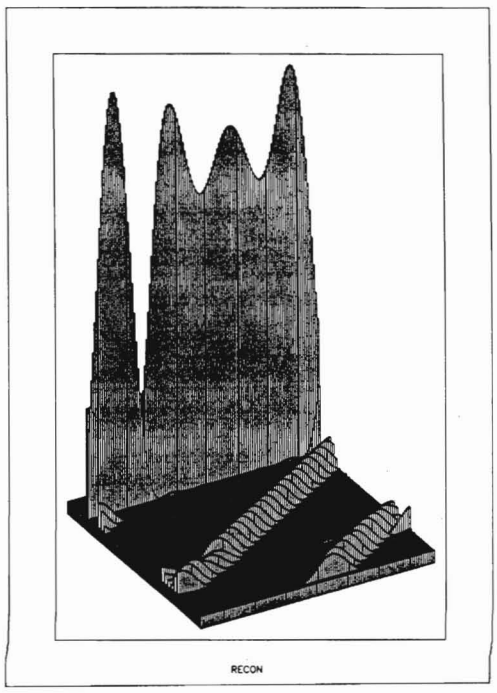

Figure 4

form. Figure 3 shows the intensity (square of correlation of a real filter with complex amplitude) immediately after a filter.

Figure 4 shows the resulting intensity for a detector. Note that a search for the parameters of the high momentum track would be greatly simplified compared to searching the original hit pattern. All pixels along the high momentum track have greater intensity than any pixel of a low momentum track, and the ratio could be enhanced with a finer filter. Figures 5 and 6 show another filter and the two tracks found within its resolution.

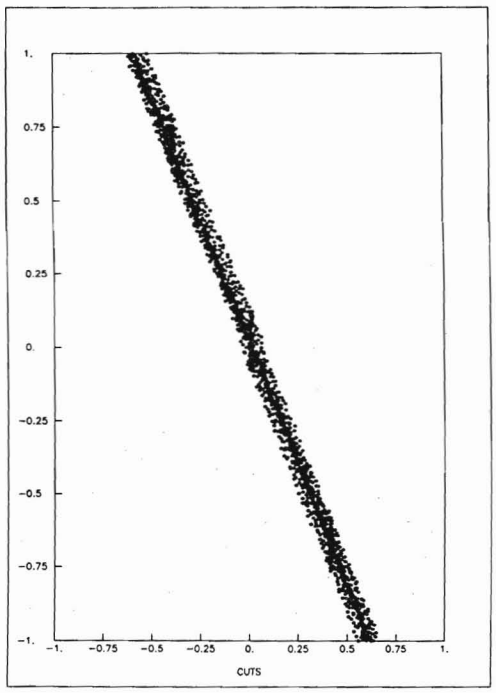

Figure 5

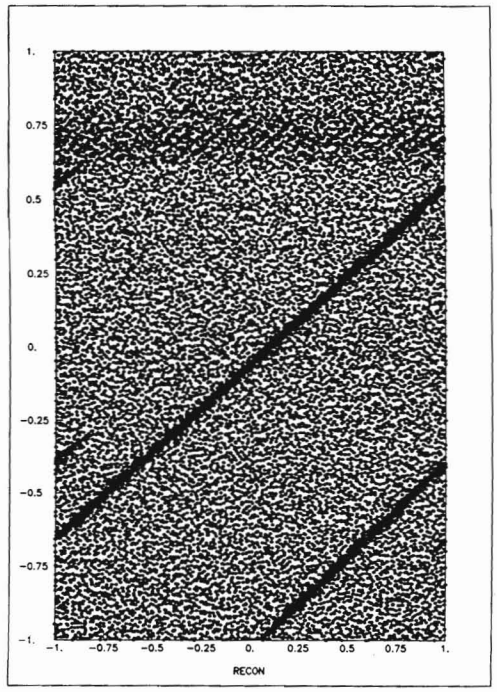

Figure 6

The time limitations in pursuing this study came from using HPLOT with DI 3000 which took over 20 seconds of VAX 785 CPU time per picture and several minutes on a laser printer. The Fourier transforms took less than 10 seconds CPU time. For actual event processing the setup, transforms, and simple searches for parameters would be the limitations.

A star ST-100 array processor would take about 17 milliseconds for the 128x128 transform. The filtering and fast searches might be amenable to vectorization.

A commercially available 128 x 128 optical device can be set up by computer in 2 ms. This is the Litton Industries Light-Mod™ array (Litton iron garnet H triggered magneto optical device). Television scan readout with a flash ADC would take 17 ms, comparable to the ST-100 processing.

To find the time required for processing all tracks in a single map with a vector processor, we might have setup (few ms?), transform (17 ms?) then iterate filter, transform back, and simple search (21 ms * 128 = 2.7 sec). The time required with an optical processor would be setup, readout, and simple search (2 ms + 17 ms + 2 ms)* 128 = 2.7 sec). If the readout could be done in parallel columns instead of 16K pixels serially read out in a television scan, the time might be considerably faster.

To find only high momentum tracks in a map, only one filter, one reconstruction, and one fast search are needed. This would take something over 21 ms per map with our assumptions or perhaps 160 ms for a complete event.

Of course, work with a tracking Monte Carlo is needed for topics such as dealing with a high density of tracks and combining 2-D projections or other information to get 3-D tracks. The possibilities of the method as a momentum filter and simply for speed or reconstruction encourage further study.

References

1. Applications of Optical Fourier Transforms, (Review Articles), edited by Henry Stark, Academic Press.

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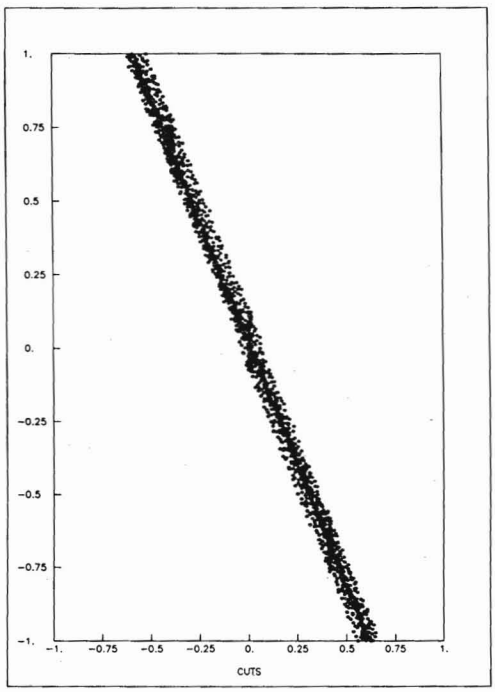

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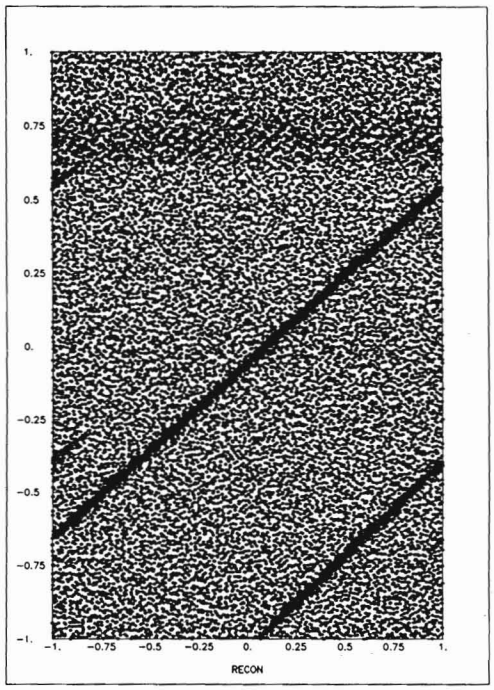

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