Nuclear Instruments and Methods in Physics Research A 834 (2016) 81–97

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

A novel approach to Hough Transform for implementation in fast triggers

Nicola Pozzobon [a,b,*], Fabio Montecassiano [a], Pierluigi Zotto [a,b]

[a] Istituto Nazionale di Fisica Nucleare, Sezione di Padova, via F. Marzolo 8, 35131 Padova, Italy
[b] Dipartimento di Fisica ed Astronomia "G. Galilei", Università degli Studi di Padova, via F. Marzolo 8, 35131 Padova, Italy

ARTICLE INFO

Article history:
Received 21 December 2015
Received in revised form
9 July 2016
Accepted 10 July 2016
Available online 14 July 2016

Keywords:
L1 Trigger
Hough Transform
Telescopes of position sensitive detectors

ABSTRACT

Telescopes of position sensitive detectors are common layouts in charged particles tracking, and programmable logic devices, such as FPGAs, represent a viable choice for the real-time reconstruction of track segments in such detector arrays. A compact implementation of the Hough Transform for fast triggers in High Energy Physics, exploiting a parameter reduction method, is proposed, targeting the reduction of the needed storage or computing resources in current, or next future, state-of-the-art FPGA devices, while retaining high resolution over a wide range of track parameters. The proposed approach is compared to a Standard Hough Transform with particular emphasis on their application to muon detectors. In both cases, an original readout implementation is modeled.

1. Introduction

Particle detectors for High Energy Physics experiments, as well as for other applications, have been demanded to feature an increasingly large number of readout channels in the latest years. This requirement for higher granularity is often associated to a higher data rate to be collected and stored for analysis. Moreover, the need of high flexibility and cost containment is moving the approach to triggered readouts from custom ASICs to programmable electronic devices such as FPGAs. A new approach to real-time data analysis, either early fast triggers or high performance noise filtering systems, is then required.

The Hough Transform (HT) is a pattern recognition technique, patented in 1962 [1], originally proposed for charged track reconstruction in pictures taken at bubble chambers. Being a rather demanding algorithm, it was discarded soon, but it has been then successfully applied for decades, in the field of computer vision, for the automated recognition of shapes and features. It has been optimized in several variants for pattern recognition on digital images, after being formalized and adapted to digital implementation. For an inclusive review see, e.g., [2,3]. Recent progresses, mainly based on clever parallelization of the process, let the HT return to its original application field, elementary particle physics, in software algorithms, e.g. for track reconstruction in the time projection chamber of the Alice experiment at the LHC [4]. In this particular case, the HT is run on different CPU platforms with an execution time of the order of 1 ms per track.

FPGAs, which constantly move to higher speed and number of available resources [5–7], provide a competitive alternative as hardware accelerators for the HT, as long as it is optimized according to the specifications of the FPGA device and to the features of the curve to be detected. The necessary computing can be designed around linear operations and histograms, i.e. counters, in the parameter space, which can both be easily implemented in programmable logic. A quite recent project foresees the HT on an FPGA to improve track parameter resolution from patterns already obtained with associative memories in the new CMS tracker for the HL-LHC [8]. Another ongoing CMS upgrade project based on the HT is the Time-Multiplexed Track Trigger, embedding a HT track finder designed around a systolic array [9].

2. Study case: telescopes of position sensitive detectors

Our study case is the implementation of the HT for straight track detection in telescopes of position sensitive detectors, usually silicon devices or drift chambers, immersed in non-negligible background.

Both silicon detectors and drift chambers are affected by noise, but each drift chamber measurement carries an intrinsic left–right ambiguity: each real track is then usually accompanied by several fake companions which are rejected by offline analysis. While actual noise figures are depending on the layout and the materials of the detector, the left–right ambiguity is unavoidable in the drift chambers. Furthermore, drift chambers are used in very large area

* Corresponding author at: Dipartimento di Fisica ed Astronomia "G. Galilei", Università degli Studi di Padova, via F. Marzolo 8, Padova, 35131, Italy.
E-mail address: nicola.pozzobon@pd.infn.it (N. Pozzobon).

http://dx.doi.org/10.1016/j.nima.2016.07.020
0168-9002/

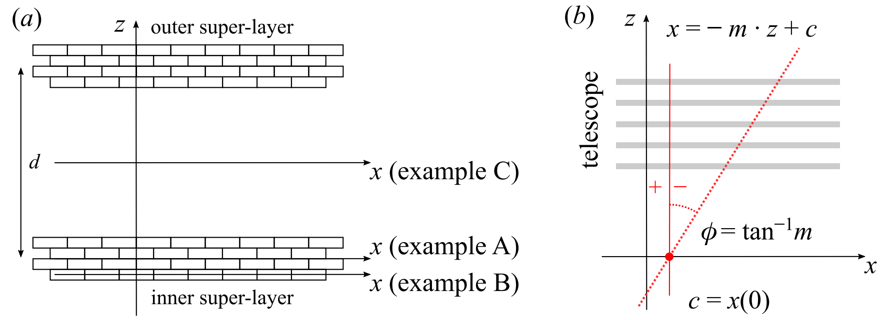

Fig. 1. (a) Layout of the CMS-like DT chamber considered as a study case. Three reference frames with different choices for $z=0$ are superimposed to the layout: such references are used in the examples of Fig. 2. (b) Representation of straight line parameters employed for the HT throughout this work in a generic layout: angles are measured with respect to the normal direction to telescope layers, and the intercept is measured on a reference plane parallel to the telescope layers.

muon detectors, and the number of measured points per track is typically lower than in silicon trackers. A small number of measured points per track is another additional challenge for good HT performance. Drift chambers are therefore an excellent study candidate for the implementation of real-time fast track reconstruction using the HT, even in an ideal situation. The results presented herein can be transposed to the analogous case of silicon detectors arrays by removing the contribution of left–right ambiguities to efficiency and resolutions, which can be expected to be better than in drift chambers. The effectiveness of HT algorithms and their robustness against spurious hits, ambiguities and noise in offline track reconstruction are known features [2]. We will instead devote our study to the development of a novel, fast and reliable approach to the HT, leading to a Level 1 Trigger algorithm.

In order to be realistic we have chosen a simplified version of the CMS muon barrel Drift Tube (DT) detector layout [10], which is a telescope of separate tracking stations, called super-layers (SL), as shown in Fig. 1(a): 8 layers of drift tubes are grouped together in two SLs, being the basic cell width $w=4.2$ cm and height $h=1.3$ cm. Given the thickness of tube walls of 1 mm, the geometrical inefficiency is 2.5% per layer at normal incidence. The distance between the inner and outer SL is $d=23.5$ cm.

Any muon crossing the detector will then provide only $O(10)$ correct input points, associated to the same amount of left–right ambiguities. An additional difficulty of the chosen layout is posed by the use of two rather distant tracking stations, causing measured points to be concentrated in space, rather than being uniformly distributed as, intuitively, would be the best situation. Anticipating the specific solution to this problem, which is addressed in Section 3.1, the designed algorithm exploits the peculiar grouping of sensitive layers with a dedicated partitioning of the input dataset. Despite being developed for a particular layout and a particular detector, the proposed algorithm can be applied to other telescope configurations, adapting it to different geometries. For instance, in an evenly distributed group of detector layers, different sets of layers can be easily generated artificially by an adequate, non necessarily consecutive, channel grouping.

An advantage of choosing the CMS DT muon detector is given by the existing L1 DT trigger [11], which is currently operating and can provide a comparison test-bench for any new development. The current muon trigger in the barrel of the CMS detector is based on a synchronous local trigger specifically designed around the described layout. Local straight track segments, being the magnetic field fully contained in the iron yoke, are built by two ASICs: the Bunch and Track Identifier (BTI) and the Track Correlator (TRACO). The BTI processor exploits the staggered-cell layout of each super-layer to reconstruct hits from the drift-times with a synchronous track fitter. The TRACO processor associates triggers from the BTI outputting track segments identified by a position in the chamber, i.e. the local x coordinate of the intersection of the track segment with the reference plane in the middle of the chamber, and a local direction, i.e. the angle between the track segment and the normal to the reference plane. Furthermore the current trigger and readout systems will be outdated at the HL-LHC and will need replacement, hence the Hough Transform could provide an alternative to this approach. The test bench is then given by the comparison between the performance of the current BTI-TRACO trigger chain and the performance of a newly proposed algorithm implementing the HT, aiming at least at the preservation of the current trigger resolution and efficiency.

We shall consider the true drift time as measured from the time of passage of the muon through the telescope, supposing that this instant can be precisely identified by a pre-trigger. If the drift time is the actually measured quantity, conversion to position is straightforward and the drift chamber can be then considered like a pure position measurement device. Unfortunately this is not the case for LHC muon triggers, where the time frame is unknown and needs to be identified by the trigger algorithm. Since our goal is the development of a fast HT algorithm applicable to purely position sensitive devices, this detector dependent complication, will not be taken into account.

A Standard Hough Transform (SHT) for finding track segments in a CMS DT chamber is presented in Section 3, addressing the peculiarities of a telescopic detector layout, while an original and more compact implementation of the HT is then proposed in Section 4 to address the need of downsizing the SHT histogram.[1] All the geometrical features of the algorithm that can affect efficiency and resolution, including the choice of coordinate system, the quality of input data, and the extraction of track parameters, will be addressed. We have not considered hits generated by electromagnetic background because they are specific of the DT chamber material. Anyway, the measured average fraction of spurious hits associated to a muon track is $O(5\%)$ per cell [12], representing a higher order correction with respect to the left–right ambiguities which are strongly correlated to every measured hit. Final efficiencies and resolutions will then be somewhat slightly biased, but general features could safely be retained. This study, even if fixing the parameters of the algorithm when needed, coherently with the aim of reproducing the performance of current CMS DT trigger, will be of more general interest, showing pathways to the tuning of the algorithm for different layouts and target performance, and general results, not depending on the specific study case, will be emphasized.

[1] Patent pending on key features of the algorithm.