Computers in Biology and Medicine 39 (2009) 119 – 129

Contents lists available at ScienceDirect

Computers in Biology and Medicine

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

Optimization of 2D image reconstruction for positron emission mammography using IDL

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ARTICLE INFO

Article history:
Received 20 June 2007
Accepted 23 November 2008

Keywords:
Image reconstruction
Iterative algorithms
Emission tomography
Positron emission mammography
IDL
ART
OSEM
MLEM
Computer implementation

ABSTRACT

The Clear-PEM system is a prototype machine for Positron Emission Mammography (PEM) under development within the Portuguese PET-Mammography consortium. We have embedded 2D image reconstruction algorithms implemented in IDL within the prototype's image analysis package. The IDL implementation of these algorithms proved to be accurate and computationally efficient. In this paper, we present the implementation of the MLEM, OSEM and ART 2D iterative image reconstruction algorithms for PEM using IDL. C and IDL implementations are compared using realistic Monte Carlo simulated data. We show that IDL can be used for the easy implementation of image reconstruction algorithms for emission tomography.

1. Introduction

Positron emission tomography (PET) is a functional "in vivo" imaging technique relying on the uptake of positron-emitting radiolabeled molecules. During the last years, PET has been extensively used to probe for cancer loci in oncological pathologies [1,2]. Recently, there has been an increased interest in the development of organ-specific PET systems aiming to improve spatial and time resolution for oncology purposes [3,4].

The Clear-PEM device currently under development in our group consists of a two-head planar detector for PET dedicated to Mammography (PEM) [5]. The Clear-PEM device required the development of specific software for image visualization and data analysis, coded from basic principles in IDL—Data Language,[1] with the objective to be used in the clinical setting in the near future. In order to achieve this objective, the software for image reconstruction needed to perform rapidly as well as being integrated in a general computer platform for image visualization and data analysis.

One of the main concerns of image reconstruction and visualization platforms is to get the most accurate result in the shortest amount of time. This allows the clinician to decide whether or not to repeat the examination or to perform a complementary examination in a timescale compatible with that of radiopharmaceutical effective half-live. In this context, the choice of the image reconstruction methods used and of their computational implementation plays a crucial role.

We have compared two different implementations of three image reconstruction algorithms using C and IDL, which is an array-oriented computer programming language that combines several useful tools for data processing and visualization.

Prior to image reconstruction, data are usually organized as sinograms (based on polar or cylindrical coordinates) or in list mode format. For the PEM detector geometry, we have chosen representing data using Cartesian coordinates. This representation produces mathematical entities known as Linograms [6]. In the particular case of the Clear-PEM image reconstruction algorithms, detector lines of response (LORs) resulting from the geometric coupling of pairs of detectors in coincidence were grouped according to three coordinates (w, u, v): the w coordinate corresponds to the axial

Abbreviations: PET, Positron emission tomography; PEM, Positron emission mammography; IDL, Interactive data language ™ ; LOR, Line of response; FOV, Field of view; ART, Algebraic reconstruction technique; MLEM, Maximum likelihood expectation maximization; OSEM, Ordered subset expectation maximization; GEANT, GEometry ANd Tracking; NCAT, NURBS CArdiac Torso; FDG, Fluorodeoxyglucose; FOM, Figure of merit; ROI, Region of interest; FWHM, Full width at half maximum; PSF, Point spread function; NME, Normalized mean error.

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doi:10.1016/j.compbiomed.2008.11.011

coordinate of the 2D plane in which the LOR is contained and u and v can be calculated, respectively, as the half of the sum and the half of the difference of the transaxial coordinates, defined as y_{d1} and y_{d2} in Fig. 1. According to these definitions, u represents the interception coordinate between the LOR and the central plane of the FOV and v is a function of the LOR's slope. For planar acquisition geometries it has been proved that the use of linograms is advantageous in comparison with the use of sinograms [7].

In order to accomplish an efficient IDL implementation, we have used some built-in IDL features allowing discarding the majority of time-consuming software loops. This is possible due to the fact that a large percentage of the linogram bins are zero. Let us define the Clear-PEM Field of View (FOV) as a square figure between the planar detectors. In this case, half of the bins of the linogram correspond to undetectable lines. To illustrate this effect, consider the linogram presented in Fig. 2(a). The upper row corresponds to the highest value of v (LORs with maximum slope). For this value of v, there is only one possible value for u while all other LORs with this slope are not detectable (Fig. 2(b)). Considering now the central row of the linogram, which corresponds to LORs perpendicular to the detector, it follows that all values of u are possible (Fig. 2(c)). By generalizing this analysis we can define regions in the linogram corresponding to allowed and forbidden LOR's, that is, allowed and forbidden regions for the detection of activity (Fig. 2(a)). In the particular case of the Clear-PEM device, and due to the detector plate dimensions and their working distance, the FOV is a rectangle instead of a square, resulting in approximately 70% of the total linogram bins having zero values.

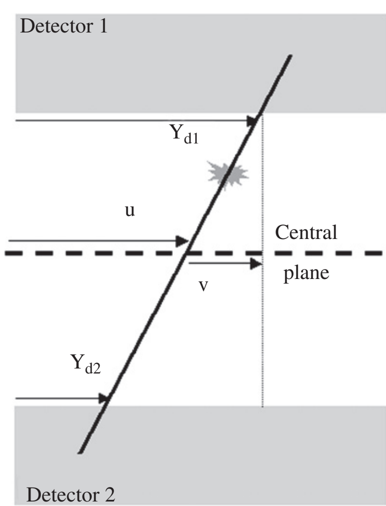

Fig. 1. Definition of linogram coordinates.

Using this information about the Clear-PEM foreseeable working characteristics, we have implemented three different 2D algorithms using linograms as input data: ART, MLEM and OSEM. These iterative algorithms require the calculation of the probabilities that photons emitted at a given point j of an object will be measured by the detection element, i [8]. In a 2D reconstruction scenario, it is possible to perform a priori calculation of these probabilities and arrange them as matrix elements (a_{ij}). We have sampled the Clear-PEM system FOV using 100×100 voxels and linograms with 100×100 bins per plane, in order to obtain voxels with approximately 1 mm^3. Therefore, we have 10 000 lines that may contribute to 10 000 voxels. In this case, if half of the bins of the linogram correspond to undetectable LORs, at least half of the total number of the system matrix elements will be zero. Additionally, a radioactive emission in a certain voxel will not contribute to all allowed linogram bins in the image. We can therefore conclude that the majority of the 10^9 matrix elements will be zero.

The implementation of the reconstruction algorithms in IDL makes use of four basic IDL features: the array manipulation with IDL operators and the functions WHERE, TOTAL and HISTOGRAM. Using these features, we achieved a large reduction of explicitly defined FOR cycles and consequently a significant improvement in execution time, when compared to our conventional implementation of the same algorithm in C. With this approach, we hoped to facilitate the data management without compromising speed, while simplifying software maintenance.

1.1. Image reconstruction in IDL

Image reconstruction is performed by calculating a very large amount of sums (see section "2D Image Reconstruction Algorithms" below). These operations are typically executed within FOR cycles

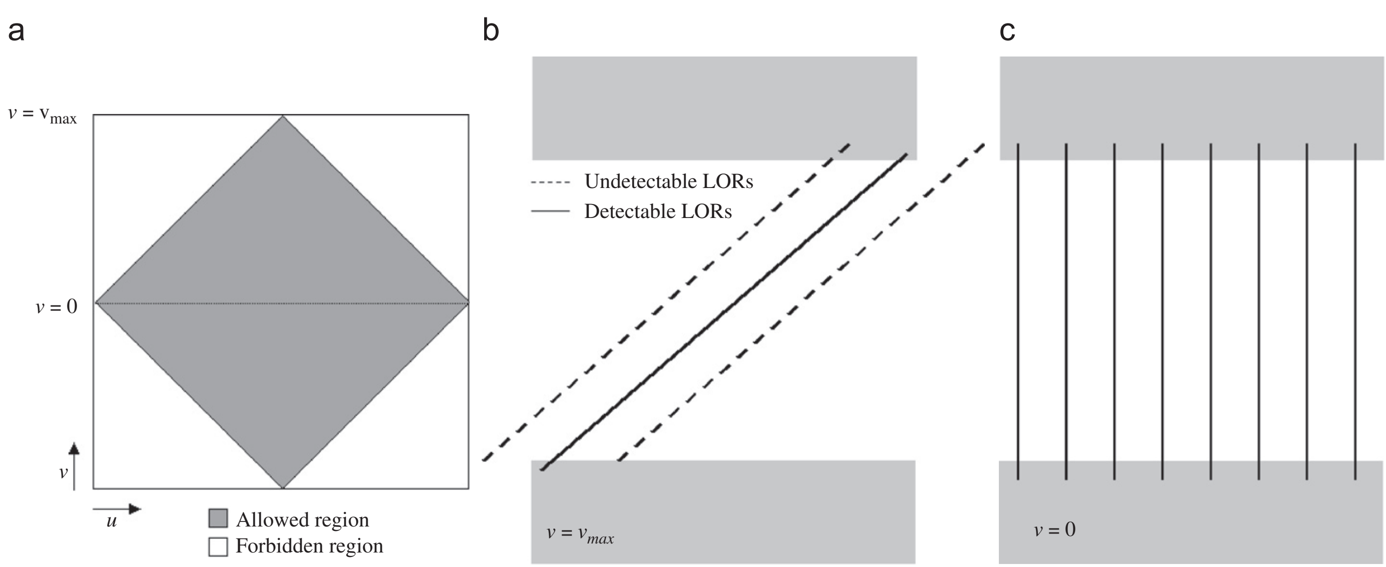

Fig. 2. Allowed and forbidden regions in the linogram (Fig. 2(a)). Examples of detectable (solid line) and undetectable LORs (dashed lines) for $v = v_{max}$ (Fig. 2(b)) and $v = 0$ (Fig. 2(c)).