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Deadtime and Pile-up Correction Method Based on the Singles to Coincidences Ratio for PET

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***Abstract*– The count rate in a PET scanner as a function of the activity in the Field of View (FOV) has a non-linear contribution coming from deadtime, pile-up and random coincidences. These effects must be estimated accurately and corrected in order to perform quantitative PET studies. For a given scanner and acquisition system, the relative importance of deadtime and pile-up effects still depends on the size and materials of the objects being imaged. These facts difficult to devise a universal correction method that yields accurate results for any kind of acquisition. In this work we show that, in a PET scanner, there is a linear relationship between the effective deadtime for coincidences, τ, (which takes into account deadtime and pile-up losses and gains within the energy window) and the Singles to Coincidences Ratio (SCRm) measured by the scanner. This relation has been recovered both in simulations and real data. This allows us to devise a simple method which, requiring only two calibration acquisitions for each energy window, one with high SCRm and one with low SCRm, is able to estimate accurately deadtime and pile up corrections for any other acquisition performed in the same scanner. Simulations show that corrected count rates are accurate within 5%, even when high activities are present in the FOV.**

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I. Proposed Method

The deadtime behavior in a PET scanner as a function of count rate can be studied by means of a decaying source experiment [1]. A uniform source containing a known quantity of a short-lived positron emitter is placed in the field of view of the PET scanner. Repeated measurements of the total coincidence rates are then made as the activity in the field of view decays. The incident count rate, n, for a given level of activity in the field of view is obtained by linear extrapolation from the count rate response measured, m, when most of the activity has decayed away and deadtime effects are small. The ratio $(n-m)/m$ then gives the fractional count rate losses and an analytic model incorporating knowledge of the system architecture is constructed, and fitted to data from decaying source experiments.

In this work we used the same method to fit (with the non-paralyzable model) not only the deadtime losses but also the pile-up losses and gains.

$$\left.\begin{array}{l} n(t)=\dfrac{m(t)}{1-m(t)\cdot\tau} \\ n(t)\cdot e^{\lambda t}=\text{constant}=[m_l]_d \end{array}\right\} \quad \frac{m(t)}{1-m(t)\cdot\tau}\cdot e^{\lambda t}=[m_l]_d$$

$$\Rightarrow \quad \frac{[m(t)]_d}{[m_l]_d}=1-m(t)\cdot\tau \qquad (1)$$

where

- m(t) Measured count rates
- n(t): incident count rate (count rates corrected by τ)
- $[m(t)]_d$: Measured count rates corrected by decay
- $[m_l]_d$: Measured count rate at low activity corrected by decay
- τ: Effective deadtime

The effective deadtime, τ, has the contribution of the deadtime (τ_{DT}), the pile-up resolution time ($\tau_{p(loss)}$) and the pile-up gains ($\tau_{(gain)}$) as follows:

$$\tau = \tau_{DT} + \tau_{p(loss)} - \tau_{p(gain)} \qquad (2)$$

In order to validate these different contributions to the effective deadtime τ, a small cylinder phantom (0.9 cm diameter, 6.5 cm length) filled with FDG in water ("water (SC)") placed at the center of the FOV of rPET scanner [2], [3] (SEDECAL Medical Systems) was simulated using PeneloPET [4]. The initial activity was 900 uCi and the count rates at different activity values were recorded.

A similar acquisition was performed in the real scanner. The initial activity was measured on a well-counter with an accuracy of ±5%. Several consecutive acquisitions of 5 minutes were taken (initial activity: 900 uCi, activity concentration: 254.6 uCi/cc, total count rate: 130 kcps, energy window: 400-700 keV).

Following S. Yamamoto et al. [5] and C.J. Thompson et al. [6], who studied the dependece of τ to the object size placed in the FOV, additional simulations were preformed to study whether the effective τ can be used for any acquisition by changing the material and size of the phantom and the energy window of the acquisition.

We found a linear relationship for each energy window between the effective deadtime, τ, and the measured Singles to Coincidences ratio (SCR_m) wich can be interpreted by a combination of two contributions: the effective deadtime if all the measured singles resulted in coincidence (i.e. $SCR_m = 2$) and the contribution that takes into account the singles which do not result in coincidences, which depends on the singles effective deadtime, τ_s, and the ($SCR_m - 2$):

$$\tau = \tau_C + \tau_s(SCR_m - 2) \qquad (3)$$

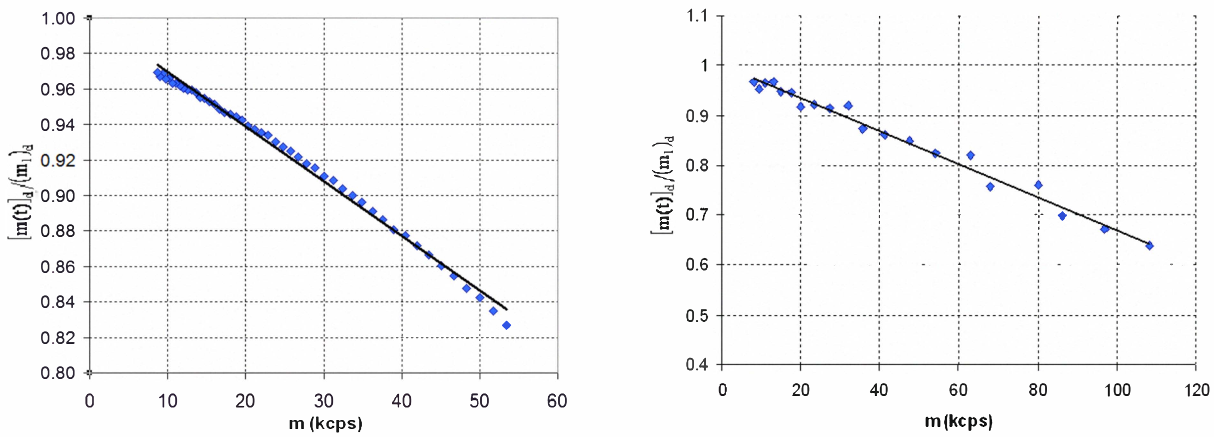
Due to the way in which coincidences are processed in the rPET scanner, this τ_s is not constant with SCR_m, because while the system is processing coincidences, no further singles can be detected. We found that, in this situation, τ_s corresponds to the singles effective deadtime when SCR_m is high.

Different distributions of activity in the FOV and different object materials and sizes were simulated to study and validate the method. Two linear fits were computed:

1) using a large cylinder ("water (LC)") filled with water (5.5 cm diameter, 5 cm length) and the "water (SC)" described above.
2) using the same large cylinder and a Point Source (PS).

II. Results

Fig. 1 shows the linear fits to compute the effective deadtime, τ, for real data (fig. 1.A) and simulated data (fig. 1.B) for the water (SC). Eq. (1) was used to fit the data. The resulting τ are reported in table I. In this table the parcial τ (deadtime and pile-up losses and gains) are also shown for the simulated data. Expression (2) was used to calculate the total τ and the value is compared with the one obtained from the fit.



(A) (B)

Fig. 1. Linear fits to compute τ using expression (1) for the "water (SC)" in 400 700 keV. (A): Real data, (B): Simulated data.

TABLE I. PARAMETERS OF THE CALIBRATION FITS ("WATER (SC)") FROM REAL AND SIMULATED DATA.

		τ (µs)	
REAL DATA	**Fit in 400-700 keV**	3.17 ± 0.04	
SIMULATED DATA	**Fit in 400-700 keV**	3.3 ± 0.1	
	Pile-up (lossess)	2.31 ± 0.08	3.2 ± 0.1
	Pile-up (gains)	0.67 ± 0.02	
	Deadtime	1.60 ± 0.01	

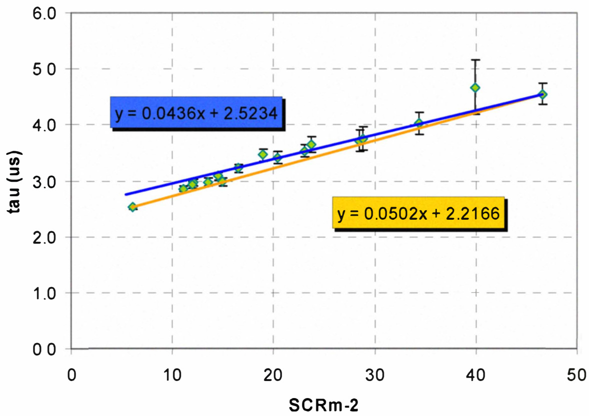


Fig. 2. Linear fits based on eq. (3) to estimate τ as a function of SCR_m 2 using simulated data in 400 700 keV. Blue: water (LC) water (SC). Yellow: water (LC) PS..

Fig. 2 ilustrates the relationship between the effective deadtime and $(SCR_m - 2)$ and the two resulting fits.

1) Blue: water (LC): $SCR_m = 49$
   water (SC): $SCR_m = 22$
2) Yellow: water(LC): $SCR_m = 49$
   P. Source: $SCR_m = 8$

Using these two estimations, we found that the best approach is the one computed with the lowest and the highest SCR_m (water (LC) –PS), having the corrected count rates an error always less than 5% for high activities.

III. CONCLUSIONS

In this work we present a simple method to correct for pile-up and deadtime the total count rates in any PET acquisition. It requires two calibration acquisitions for each energy window, one with high SCRm and one with low SCRm. We have applied it to simulations and real acquisitions for the rPET scanner, but it should be equally suitable to other kind of scanners, provided the SCR can be estimated.

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