AGATA Pulseshape Analysis Using Particle Swarms

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The AGATA detector array will consist of up to 192 36-fold segmented Germanium crystals. Each interaction of a γ-ray will result in a typical signal pattern on the segments surrounding the interaction point. The goal of pulseshape analysis (PSA) is to reconstruct not only the position but also the number of interactions and each energy deposit from the recorded signals. Because of the amount of data generated by the detector it is imperative that this analysis is carried out in near real-time. The spatial resolution needs to be 5 mm FWHM to allow the tracking algorithms to work efficiently. For the demonstrator phase the average computing time should be 10 ms or less.

1. Particle Swarm Optimization

The idea for Particle Swarm Optimization(PSO) arose from the understanding of how flocks of birds are searching for food. The complex movement of the flock is unpredictable and emerges only out of the simple behavioral rules each bird follows [1]. Every single bird is itself looking for food and steers in that direction if it found something. Simultaneously it also steers towards the perceived direction the flock is moving so that there is a balance between individual and flock search. There is no leader the flock is following.

For the algorithm the birds are replaced by abstract particles. Each particle has a position $\overrightarrow{X^t} = \{E, x, y, z\}_n$ in the search space and represents a potential solution to the problem. For AGATA it consists of the locations and energies of the n interactions. A particle moves through this space with velocity $\overrightarrow{V^t}$, which is updated at each iteration according to eqn. (1). Every particle remembers its previously best position $\overrightarrow{P_i^t}$ and at each iteration asks its neighbors for their best position $\overrightarrow{P_g^t}$. In our case these positions are those with the smallest χ^2 values.

$$\begin{aligned} \overrightarrow{V^{t+1}} &= \chi \cdot \{\overrightarrow{V^t} + c_1 \cdot r_1 \cdot (\overrightarrow{P_i^t} - \overrightarrow{X^t}) \\ &\quad + c_2 \cdot r_2 \cdot (\overrightarrow{P_g^t} - \overrightarrow{X^t})\} \qquad (1) \\ \overrightarrow{X^{t+1}} &= \overrightarrow{X^t} + \overrightarrow{V^{t+1}} \cdot \Delta t \qquad (2) \end{aligned}$$

The constant parameters c_1, c_2 are the cognitive and social parameter and govern the influence the particle's memory and the information of the swarm have on its movement. The random numbers r_1 and r_2 are drawn from the interval $(0, 1)$. The constriction factor $\chi = f(c_1, c_2) < 1$ reduces the velocities with increasing iterations to allow a finer and finer search in the vicinity of the global maximum.

1.1 Dissipative Particle Swarms

It has been observed that the classic PSO tends to reduce the velocities of the particles too quickly. The swarm hence ceases to search for improved solutions. To prevent a premature end to the search two probabilities p_l and p_v are introduced. At each iteration a random number r is drawn. If $r < p_l$ the current location of the particle is changed to a random position within the search space. Otherwise if $r < p_v$ the velocity of the particle is changed randomly. The continuous movement of the swarm leads to considerably better results [2].

2. Results

As DPSO is a stochastic algorithm the resulting distributions are not normal. An equivalent criterion to 5 mm FWHM for normal distributions is the requirement of 70% of events being within ±2.5 mm. Hence we will use the latter for the assessment of the algorithms performance.

2.1 Single Interactions

For simple cases like these a swarm of 15 particles is run for 10 iterations and achieves good results. The resulting resolutions are summarized in table 1. Due to the increasing thickness of the segments against depth the resolution in Z decreases whereas it stays constant for X and Y in the coaxial part of the detector. The computing time is 280-360 μs and well within the limits.

Coord.	Row 1	Row 2	Row 3	Row 4	Row 5	Row 6
X	89.0	75.0	86.8	89.7	85.0	88.6
Y	88.5	71.0	79.4	83.7	77.7	80.6
Z	97.4	92.4	82.6	80.1	73.0	74.4

Table 1: Resolutions as a function of depth in the detector.

The mean distance from the true interaction location varies between 1.7 mm in the front and 3.5 mm in the back of the detector.

2.2 Single Hits in Two Segments

For this case we increase the size of the swarm to 25 particles and run it for 20 iterations. The mean distance from the correct location varies between 3 and 4.6 mm depending on the combination of segments being hit. All 6 coordinates are always within the above mentioned 70 % criterion. The computing time is faster than 3 ms.

3. Conclusions

The algorithm is capable of solving the simple cases of AGATA-events in a short enough time. It also has the potential to work for multiple interactions in the same segment. It will be important to utilize any symmetries and constraints that keep the volume of the search space as small as possible.

References

[1] J. Kennedy, R.C. Eberhart, *Swarm Intelligence*, Morgan Kaufmann Publishers, San Diego, USA, 2001

[2] X.F. Xie, W.J. Zhang, Z.L. Yang *A Dissipative Particle Swarm Optimization*, Congress on Evolutionary Computation,pp. 1456-1461, Hawaii, USA, 2002