# Revisiting the Generation of Dither Times in the Context of Blended Marine Seismic Acquisition

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## Summary

Generating dither time tables for blended seismic acquisition is done through a call to a random number generator with an acceptance criterion to enforce operational and processing constraints. This approach is simple but optimality of the generated table and the non-feasibility of the solution for some constraints can be questionable. The paper addresses this problem and proposes a purely deterministic solution. First, a measure of randomness and separation of the dither-time differences is defined. Then, the optimal dither times are found which maximize this measure whilst satisfying all the constraints. The solution space is discretised, and the solution is obtained using a dynamic programming approach. The new dither times are found to be better in terms of having a flatter statistical distribution and a wider spread of their differences.

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### Introduction

Simultaneous source shooting is a standard practice in marine seismic acquisition. It helps to improve the operational efficiency and therefore reduces the cost of the survey. From a seismic processing point of view, the deblending of the sources is possible if they are encoded properly. One common approach to encode the sources is via pseudo-random dithering of their firing times (Beitz et al. 2016). The sequence of the dither times is obtained using a random number generator. Each generated random sample is accepted if its value satisfies certain constraints that may involve previous samples. The dither samples are generated and checked one by one until the sequence reaches the required length.

The dither sequence generated by this approach is not unique and depends on the initial seed of the random number generator. It simply represents a random member from the set of feasible sequences that satisfies the dither times constraints. By no means we can claim that the resulting sequence is the optimal one given any criterion. This is not an issue in itself; however, if the constraints are made tighter to ease the deblending process, we may face the risk of a broken sequence or in the best scenario we may run a huge number of realisations to get a sequence with the required length. This is not practical and can be time consuming.

In this paper we propose an alternative and purely deterministic approach to generate dither times. The new solution uses a pre-defined measure of randomness and separation and try to find the solution that maximizes this measure whilst respecting all the constraints. The problem is casted as discrete optimisation problem with constraints and is solved using a dynamic programming approach.

### Constraints on the dither times

Ignoring the natural dither, the absolute firing time of the $n^{th}$ shot is $T_n = n\Delta T + \tau_n$, where $\Delta T = \frac{dist}{V}$, $dist$ is the shot to shot spacing, $V$ is the vessel speed and $\tau_n$ is the dither time associated with the $n^{th}$ shot in the line. The values for $\tau_n$'s are random but they are constrained to void crossing the next or the previous shot, i.e., $|\tau_n| \ll \Delta T$. This defines the first operational constraint, i.e.,

$$T_{min} < \tau_n < T_{max} \qquad (1)$$

The interference of the $(n+1)$ shot in the timing of the $n$ shot appears at time $t_n$ defined as:

$$\begin{aligned} t_n &= T_{n+1} - T_n \\ &= \tau_{n+1} - \tau_n + \Delta T \end{aligned} \qquad (2)$$

The dither times are set such that the interference will come at earliest, below a specific time known as minimum clean record length ($CLR_{min}$), i.e., $t_n > CLR_{min}$. This leads to the second operational constraint defined as

$$\tau_{n+1} - \tau_n > T_{cut} = CLR_{min} - \Delta T \qquad (3)$$

with $T_{cut} < 0$. All the deblending algorithms explore the non-coherent natures of the interference sources in a domain orthogonal to the shot domain (e.g., chan, cdp, rec) which is the result of the random dithering. If we focus on the $(N+1)$ interference shot and neglect the constant bias in eq. (2) by setting $t_n = \tau_{n+1} - \tau_n$, then we need to have the samples in the sequence of the *dither times differences*,

$$\{t_k, t_{k+N_{src}}, t_{k+2N_{src}}, t_{k+3N_{src}}, \dots, t_{k+sN_{src}}\}, \text{for } k = 1,2,\dots,N_{src} \qquad (4)$$

as randomly and as distant as possible over any running window of length $L$. The parameter $L$ relates to the spatial length of the deblending operator. The method proposed by Strand et al. (2021) ensures that $|t_k - t_{k-N_{src}}| > T_{th}$ where $T_{th}$ is a time separation threshold. This represents a processing constraint. The constraint is defined with respect to a single backstep point, i.e., $L = 1$. Similar idea is described in Elboth et al. (2020) but with a slightly tighter processing constraint ($L > 1$). However, to ensure there is always a solution, $T_{th}$ is decreased for higher backsteps when the number of realisations to generate a new point exceeds a specific number. One can appreciate the fact that any tightening of the constraints, to increase the randomness and separation between the samples of the dither time differences, can lead to a solution short of the required number of samples.

**Methodology**

$\Phi_L = \{t_1, t_2, \ldots, t_L\}$ is a set of $L$ ordered samples. Let's define the following statistics that measure the level of separation between the samples of $\Phi_L$

$$D_{min}(\Phi_L) = \min_{(i,j), i \neq j} |t_i - t_j| \quad (5)$$

$$D_{avg}(\Phi_L) = \frac{2}{L(L-1)} \sum_{i=1}^{L} \sum_{j=i+1}^{L} |t_i - t_j| \quad (6)$$

$$D_{sf}(\Phi_L, T_{th}) = \frac{2}{L(L-1)} \sum_{i=1}^{L} \sum_{j=i+1}^{L} I(|t_i - t_j| > T_{th}) \quad (7)$$

$D_{min}$ and $D_{avg}$ are respectively the mean and the average time distance between the set of samples and $D_{sf}$ (separation fraction) is the fraction of pairs that are distant from each other by more than $T_{th}$. Figure 1-a shows 11 samples that are visually more distant compared to the samples in Figure 1-b. The computed above statistics confirm this (Figure 1). However, enforcing the maximization of these statistics may lead to a coherent layout of the samples as shown in Figure 1-c. This conherent structure will compromise the effectiveness of the deblending process. To overcome this problem, we introduce a non-coherecy measure. First we define an interference spike $x(t,n) = \delta(t - t_n)$ in the $TX$ domain. In the $FX$ domain, it will map to $X(f,n) = e^{-j2\pi f t_n}$. Then, we construct the spatial series $h(n) = x(f_0, n)$ where $f_0$ is a reference frequency in the seimic bandwidth. If the sequence of samples is non-coherent then $h(n)$ should be decorrelated with a flat amplitude spectrum. We capture this measure of non-coherency as follows:

$$D_{fft} = \sum_{i=1}^{\mathrm{M}} Q(i) \Big/ \mathrm{M} \quad (8)$$

In here $H = |FFT(h)|$, $Q$ is $H$ sorted in ascending order and M is 0.8 × (FFT size). Figure 1 also shows that $D_{fft}$ get smaller if the samples have a coherent layout.

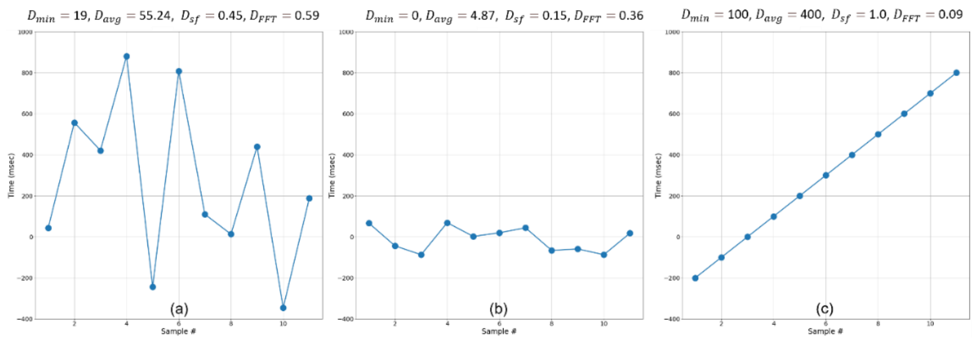


***Figure 1**. A set of samples and their corresponding measure of separation and non-coherency*

The proposed method tries to maximize an aggreare measure of separation and randomeness of the dither times differences in eq. (4) for the $N_{src}$ sources simulatanously and over all the sliding windows of length $L$, i.e.,

$$\{\hat{\tau}_1, \hat{\tau}_2, \cdots, \hat{\tau}_{N_{sp}}\} = \max_{\{\tau_1, \tau_2, \cdots, \tau_{N_{sp}}\}} \sum_{src=1}^{N_{src}} \Theta(\Omega_{src}) \quad (9)$$

where $\Theta(\Omega_{src}) = \alpha_1 D_{min}(\Omega_{src}, L) + \alpha_2 D_{avg}(\Omega_{src}, L) + \alpha_3 D_{dnr}(\Omega_{src}, L) + \alpha_4 D_{FFT}(\Omega_{src}, L) + \cdots$
under the operational and processing constraints as follows

1. $T_{min} \leq \tau_i \leq T_{max}$ for $i = 1, 2, \ldots, N_{sp}$, $N_{sp}$ is the number of shots in the sequence.
2. $\tau_i - \tau_{i-1} > T_{cut}$
3. For every window of $L$ consecutive samples in the sequence in eq. (4) we need to have

$$|t_i - t_j| > T_{th},\ i \neq j \qquad (10)$$

The coefficients $\alpha_i$'s and the threshold $T_{th}$ are supplied by the user. The third constraints in eq. (10) is much more tighter compared to all the constraints in the existing methods. The optimisation problem in eq. (9) is solved using the Viterbi algorithm (dynamic programing) after descritisation of the solution space for $\tau_i$'s from $T_{min}$ to $T_{max}$ with an appropraie step size.

**Simulation results**

The proposed solution is used to generate dither times for a triple source line ($N_{src} = 3$) with 3000 shots points using the following values for the different constrains: $T_{min} = 0$ msec, $T_{max} = 1000$ msec, $T_{cut}$ =-500 msec, $T_{th} = 50$ msec and $L = 9$. For a comparion puporse we generate the dither times with the method described in Strand et al. (2021) using $L = 1$.

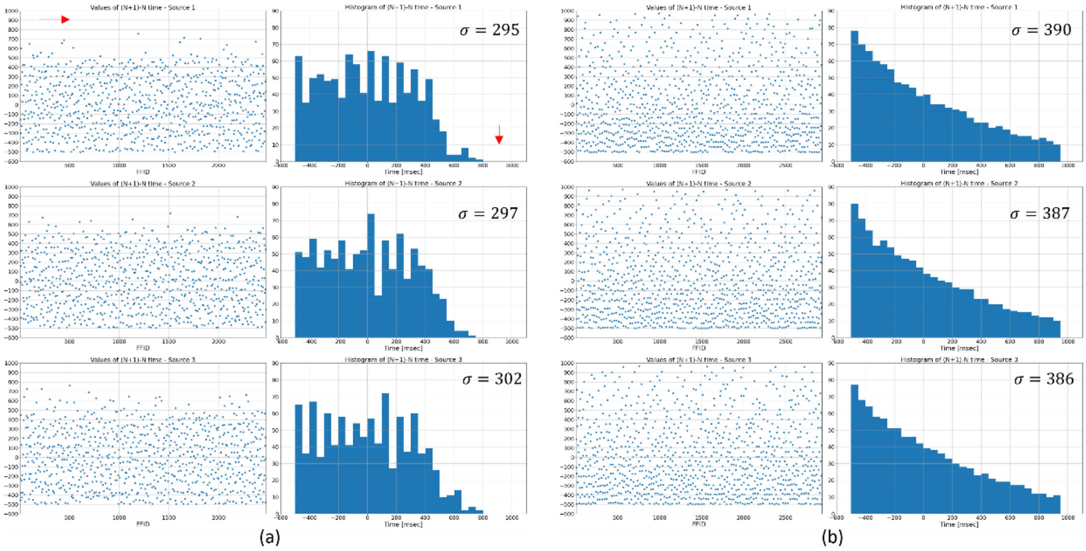


***Figure 2***. *Dither times differences (a) current method, (b) new method*

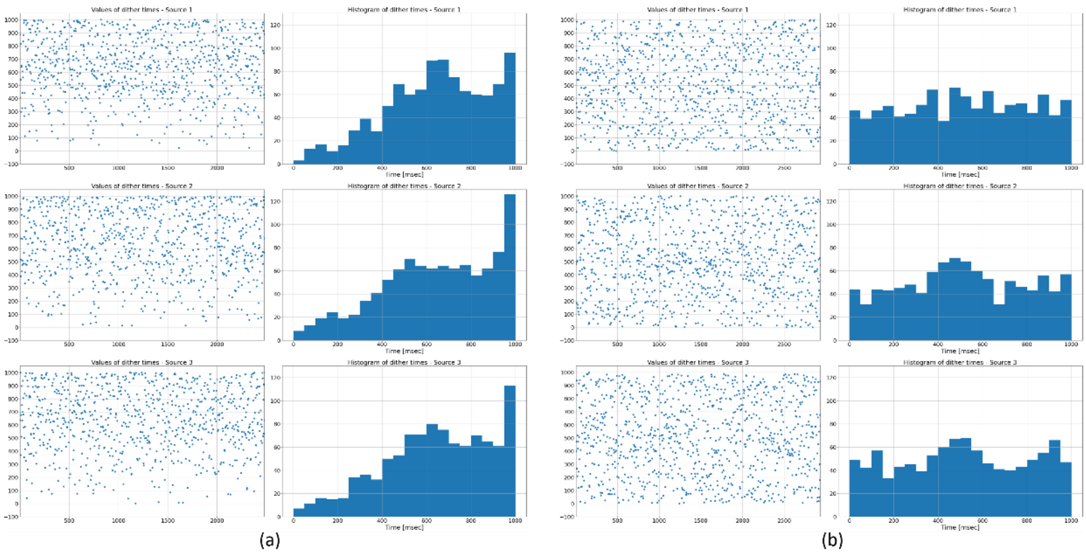


***Figure 3***. *Dither times (a) current method, (b) new method*

Figure 2 shows the dither times differences obtained by both methods. The proposed solution (Figure 2-b) acheives more variability as quantified by the Strand deviation. The scatter plots and the histograms of the result obtained by the current solution (Figure 2-a) indicate that large values for the dither time differences are not populated (nothing above 800 msec). This will not be in favour of the deblending process. There is no visible paterns on the scatter plot of the dither time differences obtained by the new solution (Figure 2-b). The distributions of the dither times generated by the current solution are skewed towards larger values, whilst the one obtained using the new method are more equally spread (Figure 3). Having a flat distribution for the dither times is desirable to achieve a uniform variation of the actual shot point locations from the pre-plot one. Figure 4 shows that the average separation between the dither time differences is larger with the proposed method for a wide variation of $L$. To assess the impact of enforced separation on the potential risk of introducing coherent pattern, we plot the non-coherency measure in eq. (8) as a function of $L$ (Figure 5). With the new method we achieve a high non-coherency scores up to a window length of 60 which is well above the usual value for the equivalent parameter used in the deblending process.

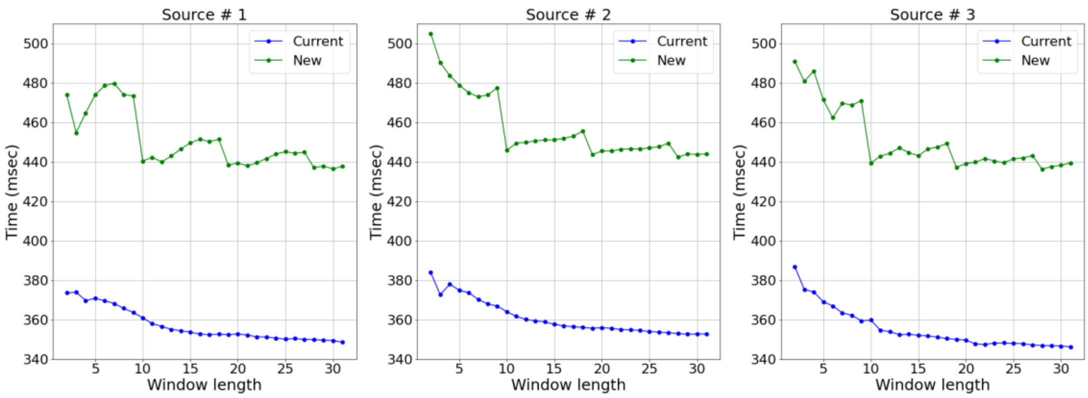


***Figure 4**. Average distance time as function of window length*

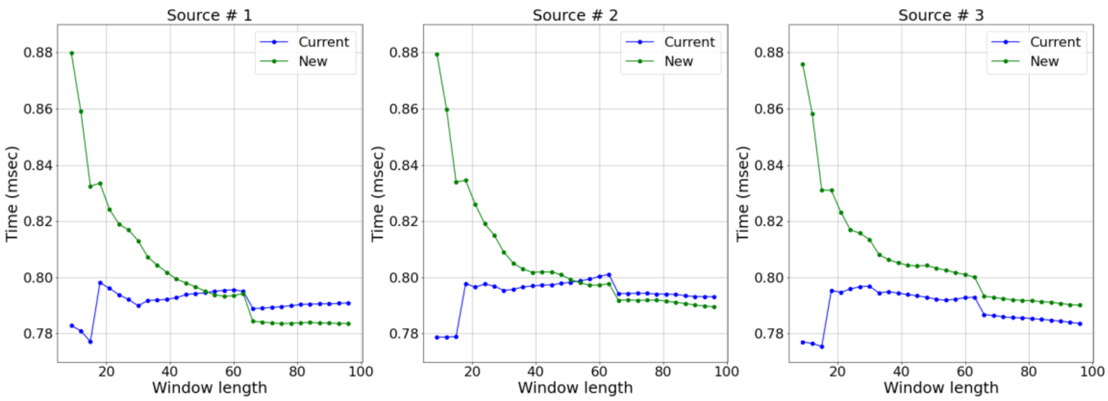


***Figure 5**. Non-coherency measure as function of window length*

## Conclusion

Generating dither times for blended seismic acquisition can be done using a deterministic approach. This approach offers a better control on the solution and a more flexible way to integrate any constraints. Enforcing tighter local constraints on the dither time differences to ease the deblending process may induce some structured patterns at a longer scale which are often larger than the deblending spatial span. Two factors affect the run time of the solution, the length of the table and the time discretisation of the solution space.

## Acknowledgement

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## References

Beitz, M., Strand, C. and Baardman, R. H. [2016] Constraint of Dithering of Source Actuations, US Patent Application Number 20180052248.

Elboth, T and Vinje, V. [2020] System and methods for generating dithering sequences for seismic exploration. US patent US10649108B2

Strand, C and Hodges, E. [2021] Shot point dithering techniques for marine seismic surveys GB patent GB2602433A