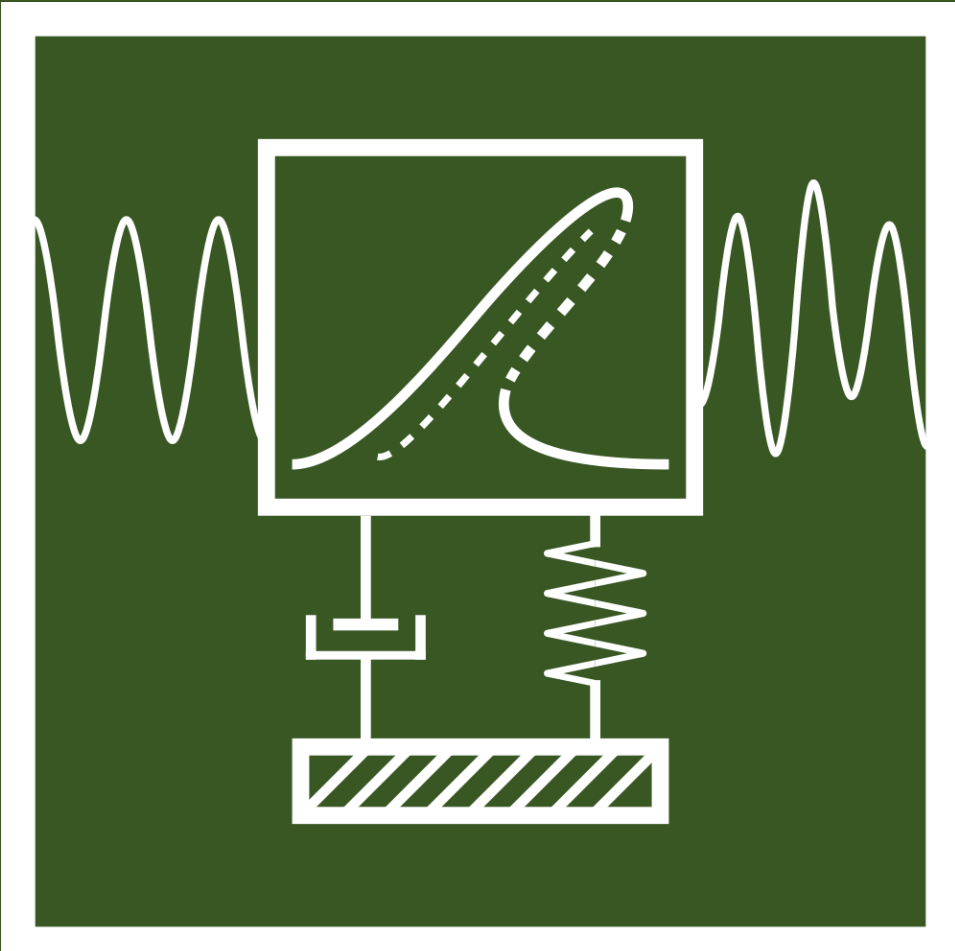


DCT-Based Fragmentary Smoothness for Fast Vibro-Acoustic Signal Comparison

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A Abstract

Vibro-acoustic condition monitoring requires the comparison of many signal fragments, but exhaustive fragment matching is computationally expensive. This poster presents a fast screening approach based on fragmentary smoothness estimates derived from the discrete cosine transform (DCT). Each signal fragment is described by a smoothness parameter that characterizes the decay of its spectral coefficients. If two fragments have substantially different smoothness values, they can be rejected before full mean-square-error comparison. Tests with rolling bearing vibration data show that the criterion can reduce the number of candidate fragment comparisons by up to 98.8 % and reveal clear differences between normal and faulty bearing conditions.

01 Methods

Each analysed signal fragment is transformed using the discrete cosine transform (DCT), and the decay of its spectral coefficients is approximated by a power-law model: $z(x) = C/x^\alpha$. The parameter α is treated as a fragmentary smoothness estimate. It characterizes how quickly the DCT coefficients decrease and therefore provides a simple numerical description of the fragment structure. Fragments with similar shapes are expected to have close smoothness estimates, while fragments with very different spectral decay are unlikely to be good matches. The screening rule compares the smoothness estimates of a range fragment U and a domain fragment V . If the absolute difference between their estimates exceeds a predefined threshold, the pair is rejected before calculating the full mean-square error: $|\alpha_U - \alpha_V| > \varepsilon_0$. Only the remaining candidate pairs are passed to the direct comparison stage. In this way, the smoothness estimate does not replace the original similarity measure; it serves as a fast filtering step that reduces the number of expensive fragment comparisons. The method was evaluated using rolling bearing vibration signals from the Case Western Reserve University Bearing Data Center.

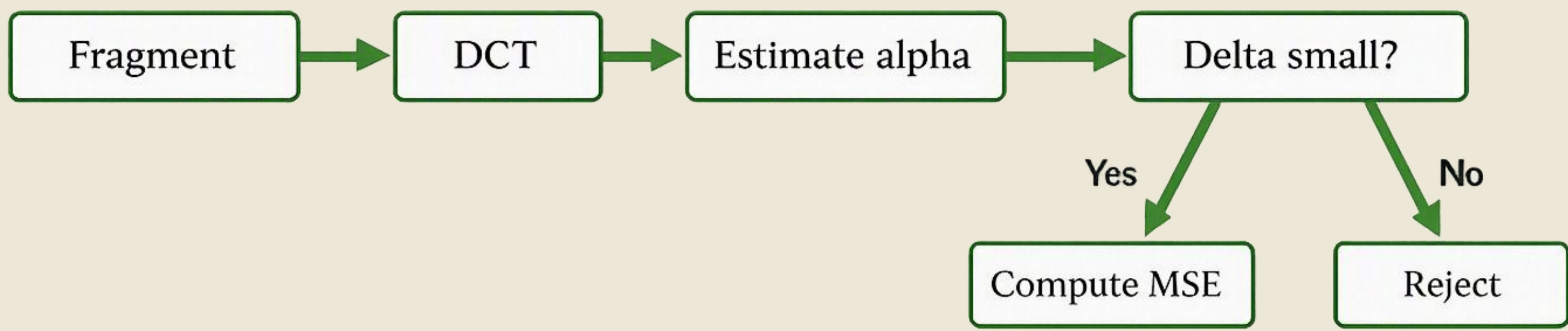


Fig 1. Smoothness-based screening workflow for fragment comparison.

02 Results

The smoothness-based screening criterion substantially reduced the number of fragment pairs that required full comparison:

Range fragment	Domain fragment	Before screening	After screening	Reduction
16	32	993	215	78.3%
32	64	961	59	93.9%
64	128	897	11	98.8%

These results show that the proposed descriptor is especially effective for larger fragment sizes, where direct exhaustive matching becomes more computationally demanding. The screening step therefore offers a practical way to accelerate self-similarity detection without discarding the final direct comparison stage. The diagnostic behaviour of the method was also visible in the grouping-centre results. For the 16-sample range and 32-sample domain case, the average grouping centre for the normal bearing condition was located at approximately (0.281, 0.033). Under faulty conditions, the centre shifted to (1.103, 0.037) for the ball fault, (1.146, 0.037) for the inner race fault, and (1.332, 0.038) for the outer race fault. This displacement indicates that the smoothness-based representation is sensitive to fault-related changes in the vibration signal structure. The largest shift was observed for the outer race fault, while all three faulty cases were clearly separated from the normal condition along the first coordinate of the grouping centre.

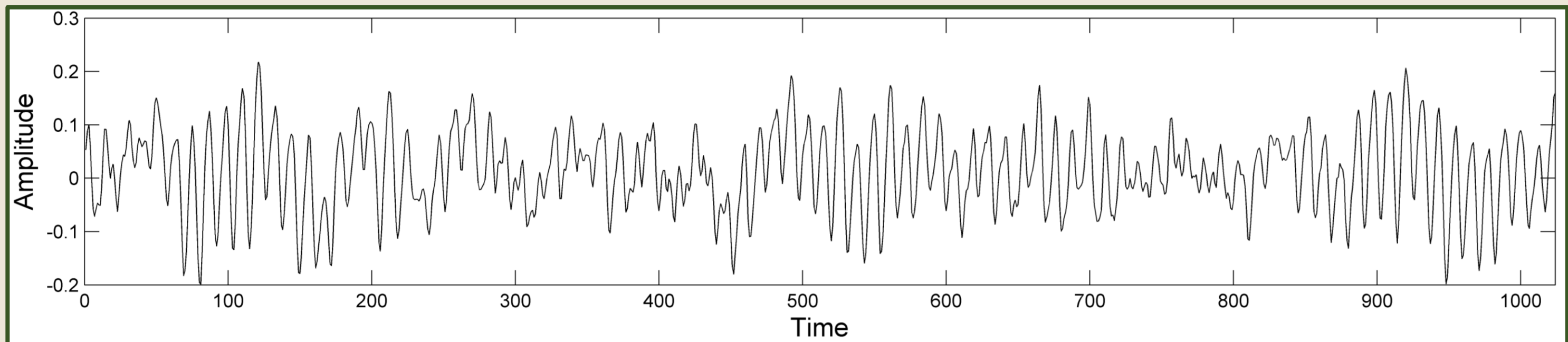


Fig 2. Vibration signals of size 1024, under normal condition.

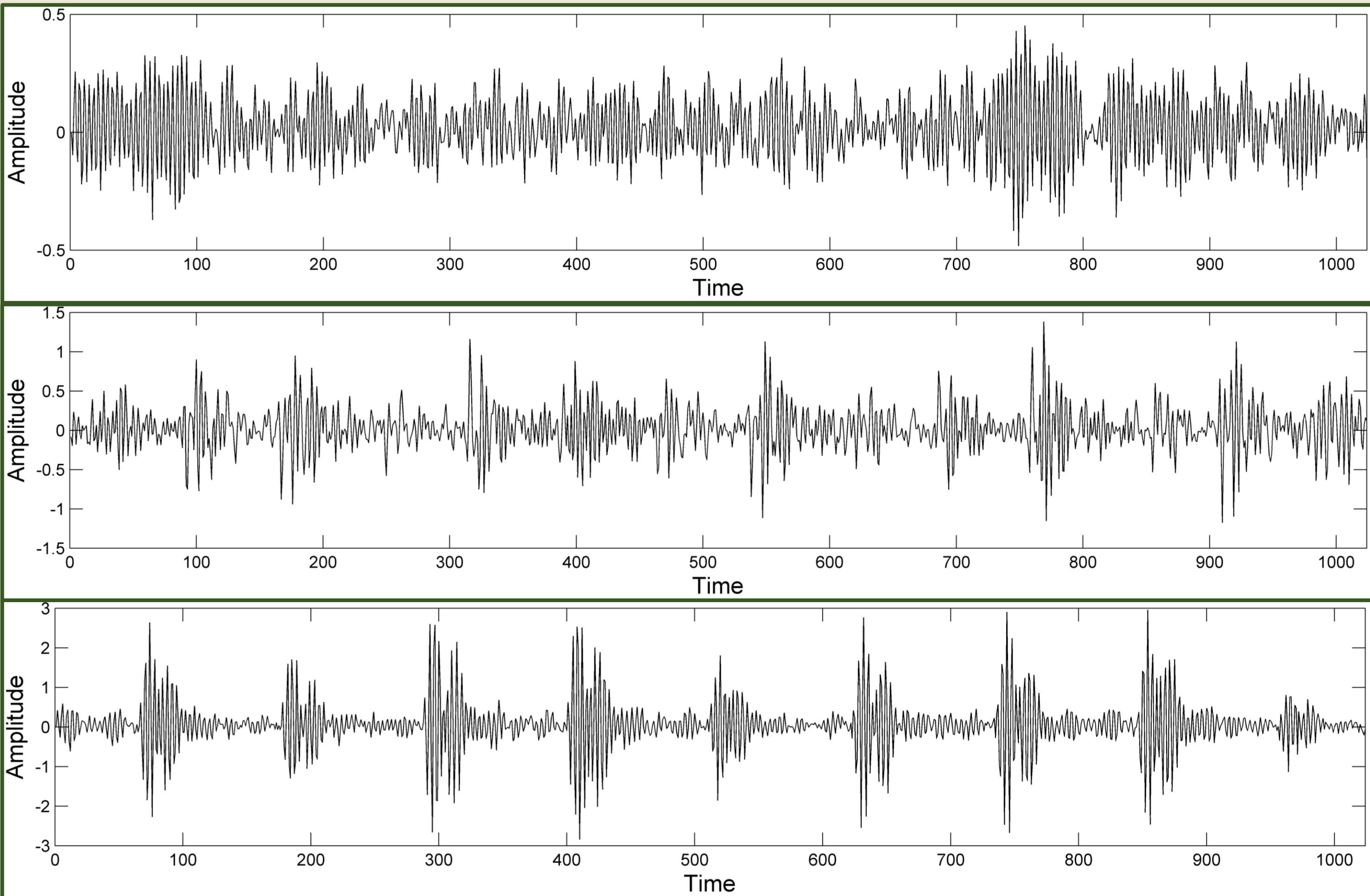


Fig 3. Vibration signals of size 1024, under ball fault, inner fault, outer fault condition.

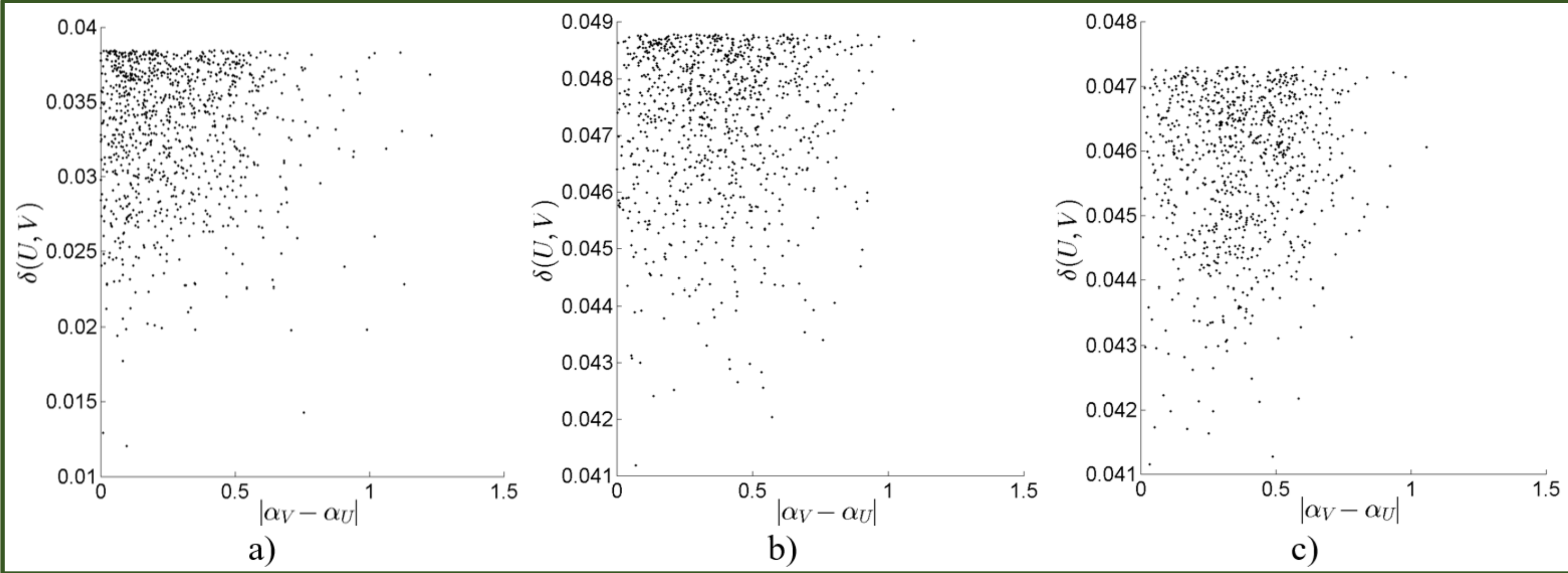


Fig 4. Search for best pairings $U \leftrightarrow V$ (normal condition): a) range fragment U of size 16 ($|V| = 32$), b) range fragment U of size 32 ($|V| = 64$), c) range fragment U of size 64 ($|V| = 128$).

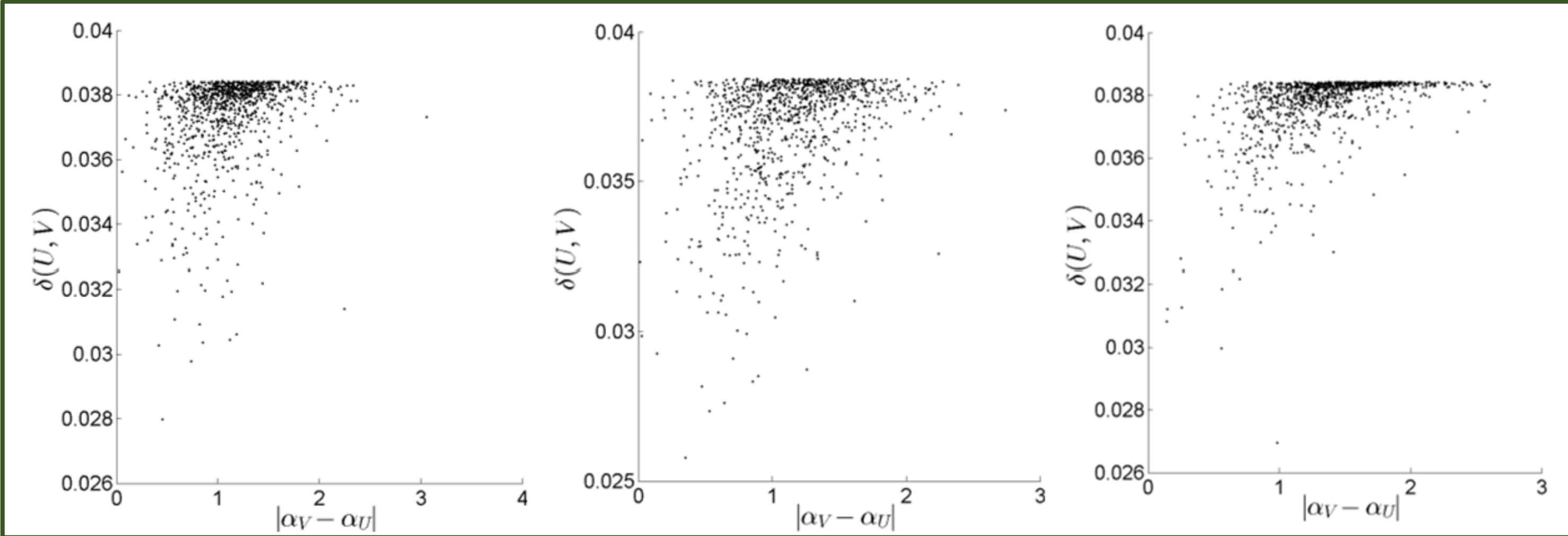


Fig 5. Search for best pairings $U \leftrightarrow V$ (normal condition vs fault condition), with the 48th range fragment U of size 16 ($|V| = 32$).

03 Conclusions

The proposed DCT-based smoothness estimate is an efficient preliminary descriptor for vibro-acoustic signal fragments. It enables unsuitable fragment pairs to be rejected before the full mean-square-error comparison, reducing computational effort while preserving the final direct comparison stage. The experiments with rolling bearing vibration signals showed a search-space reduction of up to 98.8%. In addition, the displacement of grouping centres between normal and faulty bearing states suggests that the descriptor reflects changes in signal structure caused by defects. This makes the method useful both for accelerating self-similarity detection and for supporting bearing condition monitoring.

References

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[3] Bearing Data Center. Case Western Reserve University, <http://csegroups.case.edu/bearing-datacenter/pages/download-data-file>