Fast Dynamic Time Warping for Temperature Compensation in Guided Waves

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Introduction: Temperature compensation techniques in guided wave structural health monitoring is widely researched topic as the structure is subjected to various temperature changes. Guided waves are highly sensitive to these changes, and these variations sometimes hamper damage detection performance, and sometime also lead to false alarm. Researchers are always searching for compensation techniques with excellent compensation performance. In guided wave SHM the readings are very frequent and to fully utilize the capability of guided wave inspections, the recorded signals are often quite lengthy. Due to these limitations, compensation technique must have good time/computational and space complexity. Temperature compensation algorithms such as Optimal Baseline Selection (OBS), Baseline Signal Stretch (BSS), OBS+BSS [1], Scale Transform performs well if the temperature variations are not too large, and the propagation distance is small. Dynamic Time Warping (DTW) [2] temperature compensation was also proposed but with very good compensation performance but with very high computational complexity O(N*N), where N is number of samples in each signal. In this paper we evaluate the performance of the Fast DTW algorithm for temperature compensation. The computational complexity of Fast DTW is only O(N). Objective: Stretch based method model the change in temperature as $x(t) \approx y(\beta t)$ Where β is a stretch factor resulting from temperature, where x(t) is the measured signal and y (t) is the measured baseline signal. For large temperature variation this linear stretching is not valid because large values of β stretch the data, but also incorrectly alters the frequency of the data. At higher frequency the dispersion and generation of higher modes makes it difficult to represent stretching with single starching factor β. Stretch based method also assumes that the entire structure is at same temperature, but this assumption fails in case when the structure is subjected to high temperature gradient (high pressure storage tanks while charging and discharging). The DTW method is commonly used in speech processing to assess similarity between two time series. It performs very well for accommodating variation in speech speed, pauses and breaks. This compensation is done by construction of cost matrix that maps every point in one time series to all points in the other time series. Doing so increases the complexity of the algorithm quadratically O(N*N). The Fast DTW algorithm reduces the complexity to O(N) by Coarsening, projection, and refinement [3]. Some results that compare temperature compensation in terms performance (stretch distance) and time complexity is attached in the abstract. Experiments: Two piezoelectric crystals were permanently attached to a 1 mm thick 304L stainless steel plate with dimension of 200 mm by 250 mm. Ultrasound signals were acquired in a pitch catch configuration at different temperatures (controlled in a Vötsch 7020 temperature chamber). Th signals were digitized at 40 MS/s using an ADQ214 digitizer from Teledyne SP Devices. Results: The paper will evaluate and compare the performance of the DTW and Fast DTE, both in terms of computational complexity (time) and in terms of quality of the baseline matching. Initial results show that the Fast DTW performs well and at a significantly lower cost, as indicated below: Time taken by DTW to process a sequence of length 1000, 5000, 10000, 50,000 and 100,000, respectively, are 1.19 s, 32 s, 129 s, ~1.5 hours and ~3.5 hours. The resulting stretch distance (parameter) for the sequences were found to .46, 1.4,2.0, 3.9 and 4.7, respectively. The same sequences were used with Fast DTW were 0.052s, 0.28s, 0.58s, 3.7s and 7.3 s, respectively. The stretch estimated stretch distances were exactly same for both algorithms, indicating that the baseline matching performance is also the same. In the final paper, the analysis will be repeated for more different temperatures. Conclusions: With the initial results we can clearly see that the performance of the Fast DTW is same as the DTW with huge difference in terms of time complexity as the sample length increases. References: [1] Croxford, A., Moll, J., Wilcox, P. & Michaels, J. Efficient Temperature Compensation Strategies for Guided Wave Structural Health Monitoring. Ultrasonics 50, 517–528 (2010). [2] Alexander C.S. Douglass and Joel Harley, “Dynamic Time Warping Temperature Compensation for Guided Wave Structural Health Monitoring” IEEE Trans. Ultrason., Ferroelect., Freq. Control, Mar 2018. DOI: 10.1109/TUFFC.2018.2813278 [3] Salvador, S., and P. Chan, 2004. FastDTW: Toward Accurate Dynamic Time Warping in Linear Time and Space. In KDD workshop on mining temporal and sequential data