An Accurate Auto-diagnosis Algorithm for Time-of-Flight Estimation in Ultrasonic Measurements based on empirical mode decomposition

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Ultrasonic time-of-flight (ToF) is a key parameter utilized for distance measurement in various fields including robotics, medical imaging, and non-destructive testing (NDT). Signal processing techniques, including wavelet filtering and neural network algorithms, have been utilized to remove the noise and enhance the accuracy of ToF measurements. Nonetheless, it is still challenging to achieve a comprehensive auto-diagnosis of ToF, particularly when excluding artificial assistance owing to signal interference. The current approaches necessitate skilled personnel for signal identification, adhere to stringent device requirements (such as the number of ultrasonic probes), and show the limited real-time performance. The present study aims to address the aforementioned issues by proposing a real-time auto-diagnosis algorithm for ToF estimation with high accuracy. This algorithm has the potential to minimize the need for manual operations in high-risk environments including those with high temperatures and pressures. The proposed automatic diagnosis algorithm employs wavelet filtering to mitigate external interference. Next, it utilizes empirical modal decomposition to decompose the signal in the frequency domain and select the desired signal at a specific frequency via automatic comparison. The Hilbert transformation is applied to the selected signal to obtain its corresponding envelope in the time domain. The presence of fewer vibrations and spurs in the envelope is crucial for minimizing estimation errors in auto-diagnosis, which is accomplished using spline interpolation to smooth the signal. The ToF is then calculated utilizing the peak-finding algorithm developed in this study. To show the significance of the work, two identified objects were chosen as testbed: a steel pipeline with a wall thickness of 7 mm and a 10 mm-thick 304 stainless steel (304SS) plate. The auto-diagnosis algorithm automatically calculates the data from 50 single-point tests conducted using a 5-MHz ultrasonic transducer triggered by a pulser-receiver (CTS-9009PLUS) under a constant pressure. Unlike the conventional approach, the newly proposed algorithm demonstrates the capability to accomplish a thorough self-diagnosis of ToF. Furthermore, a cross-correlation method, predicated upon an automated peak detection technique, was employed to further validate the viability of the proposed algorithm. The algorithm enables the accurate automatic estimation and reduces the error from 0.48% to 0.25% for the 304SS plate and from 2.38% to 1.25% for the steel pipeline, respectively. This is crucial for the implementation of intelligent fully automated NDT and precise ultrasonic imaging in the future.