RESONANT PEAK DETECTION ALGORITHM IN STRCUTURAL HEALTH MONITORING

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Abstract - *Wireless sensor networks are used for Structural Health Monitoring as they are more flexible, cost effective and portable as compared to their wired counterparts. The paradigm shift has been made possible by improvement in hardware and software co-designs. During the last decade there has been a lot of emphasis on bringing the laboratory experiences and research efforts into realistic SHM applications. Starting from simple Root Mean Square Deviation, Cross correlation, Standard Deviation Algorithms which detected damage conditions only the shift is toward more sophisticated feature extraction and discriminating algorithms based on inverse relationships. These are able to relate structure parameters to the analyzed output responses of the sensor node using neural network approach or genetic algorithms. In all these there has been emphasis on finding damage types and their locations so that early remedial measures can start. We have designed a simple algorithm that can work on reduced storage complexity and time complexity and can be effectively used in the initial stages of damage. Later more sophisticated algorithms can be run to have better picture of the damage condition.*

Key Words: SHM, Wireless sensor networks, RMSD, RPD, Corrosion.

1. INTRODUCTION

The raising of modern physical infrastructure in the form of bridges, buildings, dams etc. requires a lot of expenditure in the form of money, men and maintenance. The risk of environmental degradation and natural disasters like earthquakes requires intelligent autonomous monitoring. The technological development in the field of Wireless sensor networks, particulary sensor node hardware and software designs have given new impetus to better solutions.[3][4][6] The focus is on designing integrated autonomous sensor nodes with optimized sensing, local computing/decision making, memory, actuation and wireless transmission [4][6]. To conserve energy in the sensor node several strategies have been adopted e.g. energy harvesting using ambient vibrations and temperature, battery life management strategies using synchronized SRAM and ADC or sleep/wake-cycle scheduling, and efficient processing of data and local decision making.[7][8] In this paper, we focus on the last aspect of designing a lesser time consuming damage detection algorithm with reduced data storage requirements.[2] The impedance measurement based AD5933 chip has been used to do the sensing and pre-processing job.[9][10] On the basis of data processed by this "sensor patch", further processing for damage detection is done by the newly devised Resonant Peak Detection (RPD) Algorithm. It has been christened so since it detects shift in damage resonant peak with reference to baseline resonant peak for the structure material.

1.1 THE DAMAGE DETECTION ALGORITHM

The electromagnetic impedance (EMI) method has been found to relatively immune to environmental factors and boundary conditions in SHM appliactions[5]. Also EMI technique based AD5933 chip is a precision, portable and cost-effective solution to sensor node design[10]. The AD5933 impedance measurement chip has been designed for autonomous active operation – actuating the piezoelectric patch, computing the FFT of the sensed input data , and outputting the amplitude(impedance) signal for the whole range of 500 frequencies selected for damage detection. (Fig. 1, Park et al.,2010) [1]. The traditional algorithms like RMSD use the complete frequency sweep protocol to evaluate damage condition in the structure for which the RMSD metric is defined as:

$$RMSD = \sum_{i=1}^{500} \sqrt{}[(Z_{1i} - Z_{0i})^2 / Z_{oi}^2 ;$$

where Z_{0i} = Impedance corresponding to healthy (baseline)condition

Z_{1i} = Impedance corresponding to damage condition

Herein we have devised a damage detection algorithm which does not need to do complete frequency sweeps for generating output impedance profiles. Instead, in the initial scan, it gets hold of the resonant peak of baseline impedance profile. Thus, in every other scan, it starts the frequency sweep originating from this peak only. It uses a simple peak picking algorithm based on linear differences between consecutive frequency point impedances. When the peak is obtained, the first differential reduces to zero i.e. the difference between impedance values reduces to zero. We use second order differential to get hold of maxima.

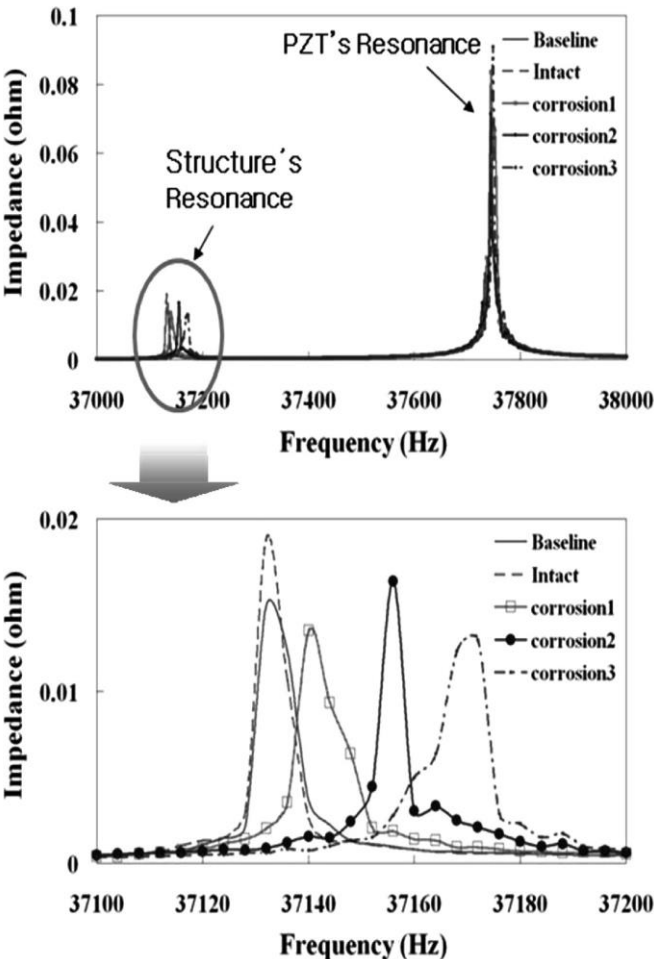

Fig -1: Variation of impedance signatures due to corrosion damage [1]

A damage detection algorithm must endeavour to reduce these computational tasks emerging out of statistical nature of the readings involved. Specifically, following points are covered in the proposed algorithm:

1) The sensor node is continuously monitored for observing peak response corresponding to resonant frequency at which the impedance amplitude value is that of intact structure. If such values are anticipated, then probably no faults are emerging and node is to be infrequently visited (remains in idle mode most of the time).
2) If some shifts are observed, the node is to be put in exploring state – whether these correspond to one of these three cases:
    a) trivial shifts
    b) intermediate shifts
    c) critical shifts
3) If trivial shifts, then go back to step 1
4) If intermediate shifts, constantly sense, but with the sweep starting from the frequency for peak value of intact case; this would eliminate scanning for redundant frequency responses till the peak frequency – only positive shifts are anticipated , and they are the only that matter.
5) If shifts are detected for the critical case, then again the start frequency is set to peak value for intact case, and sweep is completed again – this is done a number of times, to eliminate false positives. If after a sufficient number of iterations, the response is still critical (peak shift crosses threshold)- it is here that reference RMSD value is consulted to decide whether threshold is actually crossed. Thus RMSD value for complete frequency sweep impedance profile is used only as the last resort to ascertain the criticality of damage event. At this point, we send the obtained all important information to BS, for further action (decision).

1.2 The pseudo code for Resonant Peak Detection Algorithm Sub

An algorithm that utilizes only peak to shift as operating range loads the appropriate start frequency in the concerned AD5933 register, and decide dynamically on when to end the frequency sweep (Fig. 3). Here we use the strategy to compute nine rounds of RPD Algorithm in a ten round cycle after running the RMSD algorithm once. However, if damage is detected during a particular round of RPD, it abandons the rest of cycle and immediately reverts to RMSD. This shall increase the reliability of damage detection process without sacrificing on energy conservation needs of the sensor node.

```
At each Node level:
For each individual Sensor node S1 using AD5933 IMPEDANCE MEASUREMENT chip, perform the following steps:
        Inputs:
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```
        1. Initialize the start frequency value, $F_{i=1}$ = 37100 Hz;
        2. Set the step-size frequency value, Fs = 0.2 Hz;)
    Output: 1. Impedance profile of healthy structure/material, $Z_{Fi}(i=1 - < 36)$
               /Impedance profile of damaged structure/material $Z_{Fi}$ (i = 1 - 36)
while (successive rounds in operation/ damage condition not reported)
    for (i = 1 – 36)
        Step 1: A) 1. Load start frequency, $F_{i=1}$ (start / updated)
                //Perform a frequency sweep i.e. provide excitation frequencies beginning with start frequency to structure location
            2. Load the step frequency, $F_s$
                // Moving forward (adding to previous) in steps, so that updated frequency becomes present frequency in next loop.
            B) The microcontroller issues a command to AD5933 to start frequency sweep
        Step 2: 1. Identify frequency response set, $Z_{F i}$, , corresponding to each frequency, Fi, as sweep
                progresses , and
            2. Store in a look- up table
                // Impedance values set vs the programmed frequencies set
        Step 3: Keep the successive impedance differences in table along with present impedance in the same look-up table
                //Move forward in sweep by finding impedance variations,
                $Z_{Fn} – Z_{Fn-1}$
                // Impedance differences corresponding to successive frequency points , $F_n – F_{n-1}$ ,
                // Store these values in a look-up table in memory
            If( $Z_{Fn} – Z_{Fn-1}$ <= 0 ? )
                // detecting the “Peak Response”
                // $Z_{Fn}$ = Impedance at peak; $Z_{Fn-1}$ = Impedace at previous point
                // At peak, the impedance value saturates, i.e. the difference between present impedance and previous impedance value reduces to less than or equal to zero.
                Go to step 4
            else
                Move forward in sweep
                // AD5933 is already programmed to perform the sweep
            end
        Step 4: Ascertain whether we are past peak (i.e. Intact or corrosion case peak) by moving one
                step forward and backward in sweep
            If ($Z_{F n+1} – Z_{Fn}$ < $Z_{F n} – Z_{Fn-1}$ )
                1. Set start frequency at Fn-1
                   // one step before peak
                2. Set end frequency at Fn+1
                   // one step ahead of peak
                3. Start scan “around” the peak
                4. Perform the scan 4 times
                5. Average the 4 values at peak and find $Z_{Fn}$
                6. Set this value as peak value.
            else
                Go to step 1
            end
        Step 5: Compute the difference between peak values corresponding to intact case and detected
                case
            If (difference < threshold)
                Report the peak value to CH
            else if ( difference > threshold
                Report the damage case to CH
                Start process for RMSD Algorithm
                Exit
            end                               // end of if loop
        Step 6: Update start frequency to Fn i.e. the baseline peak frequency point.
            Go to step (1) for next round of measurements.
end                                           // end of while statement
```

Fig -3: The pseudo-code for RPD algorithm

2. ANALYSIS

2.1 Analytical/Numerical Simulation

1. Resonant Peak Detection(RPD) Algorithm
   Time in running of the algorithm is T_{RPS} = 1257.25 μsec.

For a Ten Round Cycle; Actual Time consumed = T_{RPS} x No. of rounds/cycle + T_{RMSD} x round/cycle

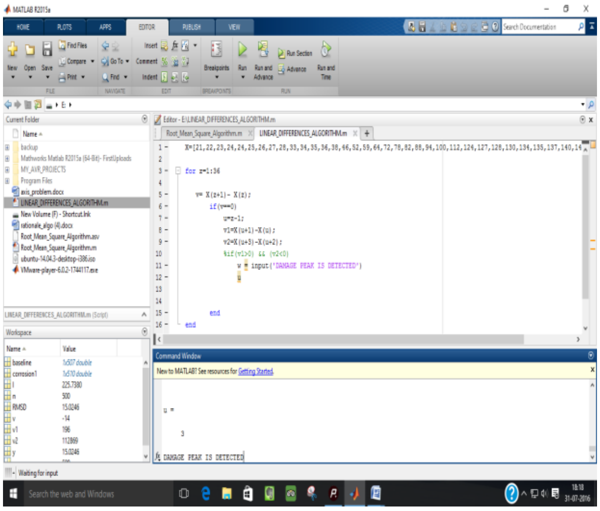
= 1257.25 μsec x 9 + 146997.50 μsec = 148254.75 μsec

2. Time in running of the algorithm is T_{RMSD} = 146997.50 μsec.

For a Ten Round Cycle; Actual Time consumed = T $_{RMSD}$ x No. of rounds/cycle = 146997.50 µsec x 10 = 1469975.0 µsec.

2.2 Software Simulation

Matlab Simulator v R2015a was used to perform simulations for the RMSD Algorithm and RPD Algorithm. The run time and debugging results were obtained during compilation of the Matlab code for the two algorithms. The RMSD algorithm execution time was found to be 2.8 us whereas RPD Algorithm executed in 0.75 us. Thus we find that there is 73.2 % reduction in time complexity which is in agreement with analytical results. The snapshots are provided herewith. (Fig 4 & 5)



```
X=[21,22,23,24,24,25,26,27,28,33,34,35,36,38,46,52,59,64,72,78,82,88,94,100,112,124,127,128,130,134,135,137,140,14

for z=1:36

   v= X(z+1)- X(z);
       if(v==0)
          u=z-1;
          v1=X(u+1)-X(u);
          v2=X(u+3)-X(u+2);
          %if(v1>0) && (v2<0)
             w = input('DAMAGE PEAK IS DETECTED')
             u


       end
end
```

Name	Value
baseline	1x507 double
corrosion1	1x510 double
l	225.7380
n	500
RMSD	15.0246
v	-14
v1	196
v2	112869
y	15.0246

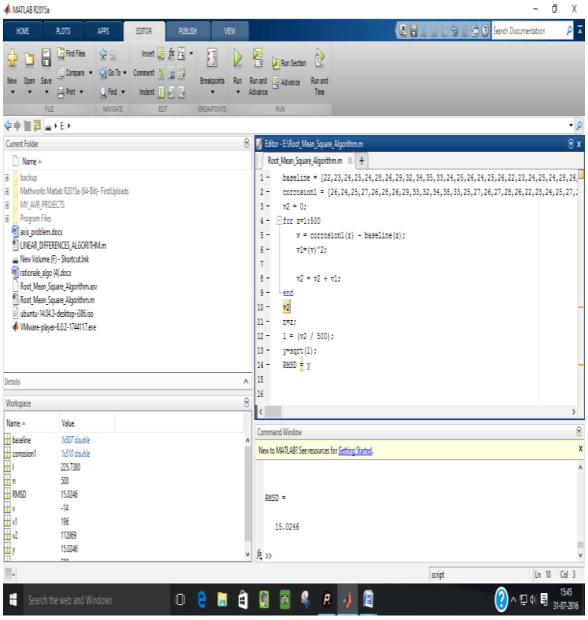
```
New to MATLAB? See resources for Getting Started.

u =

     3

DAMAGE PEAK IS DETECTED
```

Fig -4: Simulation Window for Resonant Peak Detection algorithm



```
baseline = [22,23,24,25,24,28,26,29,32,34,35,33,24,25,26,24,25,26,22,23,24,25,24,28,26,
corrosion1 = [26,24,25,27,26,28,26,29,33,32,34,38,33,25,27,26,27,28,26,22,23,24,25,27,
v2 = 0;
for z=1:500
    v = corrosion1(z) - baseline(z);
    v1=(v)^2;

    v2 = v2 + v1;
end
v2
n=z;
l = (v2 / 500);
y=sqrt(l);
RMSD = y
```

Name	Value
baseline	1x507 double
corrosion1	1x510 double
l	225.7380
n	500
RMSD	15.0246
v	-14
v1	196
v2	112869
y	15.0246

```
New to MATLAB? See resources for Getting Started.

RMSD =

   15.0246

>>
```

Fig -5: Simulation Window for Root mean Square Deviation Algorithm

3. CONCLUSIONS

On the basis of analytical results we find that there is nearly 89.91% reduction in time required to complete a single round of the LDPD algorithm as compared to RMSD damage detection algorithm. The software simulation results were found to be The results are on expected lines. The RPSD algorithm shift shows absolutely improved time savings close to 100 % as it expects to reach to first incipient damage case peak (for the example taken) using simple first order differentials. However this is an ideal case not realized in practice, since due to statistical parameters like temperature and other boundary conditions, the shift in peak is not that quantifiable. Still it gives some assessment of integrity of the structure.

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