Unstressed passive wireless sensors for structure health monitoring

Xie Liyu & Yi Zhuoran
Department of Disaster Mitigation for Structures, Tongji University, Shanghai, China

Xue Songtao
Department of Disaster Mitigation for Structures, Tongji University, Shanghai, China
Department of Architecture, Tohoku Institute of Technology, Sendai, Japan

ABSTRACT

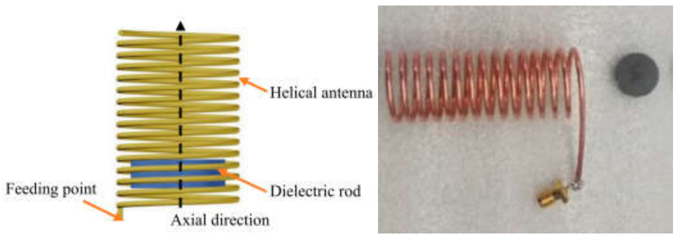
Structures may be affected by aging changes in strength and stiffness [1]. With the increasing of the service time, structural health monitoring for aging structures is progressively becoming significant [2], and variety sensors are applied to confirm the workability of aging structures.

Traditional sensors for structural health monitoring always use cables to supply power and transmit data. These wired sensors usually show a good performance in stability and accuracy. However, they are limited by the instrumentation time and system cost. By eliminated cables from traditional wired sensors and applied antennas as sensing and interrogating parts, passive wireless antenna sensors are easier to install and cheaper, which are meaningful for distributing sensors over a large area with high density.

In recent years, there has been an increasing interest in the development of antenna sensors for variety physical quantities. Due to the advantage of simple configuration and multimodality, patch antenna is usually adopted as the sensing and interrogating part. In general, the physical qualities can be obtained by analyzing resonant frequencies of the patch antenna, which would be shifted by the deformation or environment changes of the monolithic patch antenna. Yi. et al [3] presented a wireless strain sensor based on monolithic patch antenna. The antenna sensor is attached on the surface of structures and the strain of the structure is obtained by measuring the resonant frequency shifting of the patch antenna. Huang et al [4] demonstrated a patch antenna sensor that can detect crack propagation with sub-millimeter resolution by analyzing the relationship between the crack width and resonant frequency shifting in longitudinal and transverse direction. Mohammad et al [5] proposed a patch antenna based shear sensor. Tchafa et al [6] proposed a patch antenna based sensor to determine the changes in strain and temperature from the normalized antenna resonant frequency shifts. these monolithic antenna sensors show a good accuracy, but all of the antenna in these sensors is stressed.

For the stressed antenna sensor, two major drawbacks are the issues of incomplete strain transfer ratio and insufficient bonding strength. To overcome these issues, several unstressed antenna sensors was proposed, which is shown as follows.

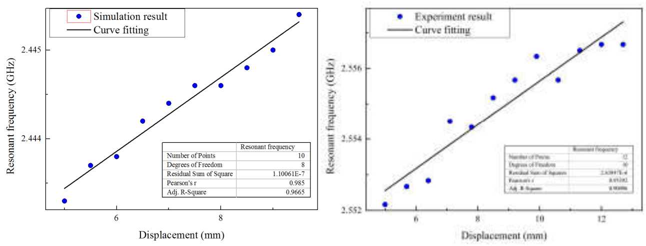
A helical antenna based passive displacement sensor is put forward by authors [7]. This antenna sensor is consisted of a normal mode helical antenna and an inserted silicon rod, which is shown in Figure 1.



(a) (b)

Figure 1. Figures of a helical antenna based displacement sensor (a) Concept Figure; (b) manufactured antenna sensor.

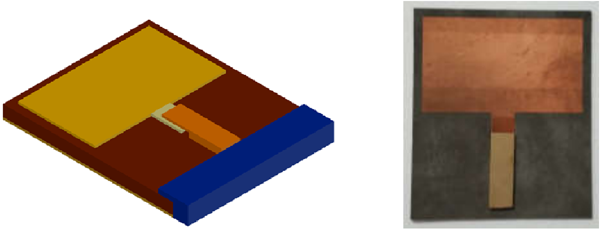
The electromagnetic field can be altered when the silicon rod dislocated, which would lead to the resonant frequencies shifting of the helical antenna. Hence, the location of the silicon rod can be certified by analyzing the resonant frequency shifting without exerting stress to the antenna. The simulation and experimental results are shown in Figure 2, which suggested a maximum effective measuring range of 7 mm with an average sensitivity of 0.616 MHz/mm.



(a) (b)

Figure 2. Resonant frequency with respect to displacement of the sensor in each group (a) Simulation result; (b) Experimental result.

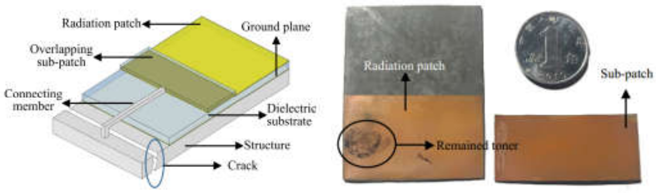
The resonant frequency of a patch antenna would be affected by the antenna loading. Based on this principle, the authors have proposed a crack width sensor by forming a parallel plate capacitor using two microstrip lines as a sensing unit, which is shown in Figure 3[8]. As the relative movement of two microstrip lines is analyzed instead of the deformation of a monolithic antenna, the antenna is unstressed.



(a) (b)

Figure 3. Figures of a patch antenna based crack width sensor (a) Concept Figure; (b) manufactured antenna sensor.

Another similar unstressed crack width antenna sensor was proposed by combined a monolithic patch antenna with a movable radiation patch, which is shown in Figure 4[9]. The total length of the combined radiation patch would be altered by the relative movement between the patch antenna and the dielectric board, leading to a shift of resonant frequency in the sensing system.



(a) (b)

Figure 3. Figures of another patch antenna based crack width sensor (a) Concept Figure; (b) manufactured antenna sensor.

Theory calculation, simulation and experimental results show an effective measuring range of 1.5 mm with a sensitivity of 120.24 MHz/mm on average, which is presented in Figure 5.

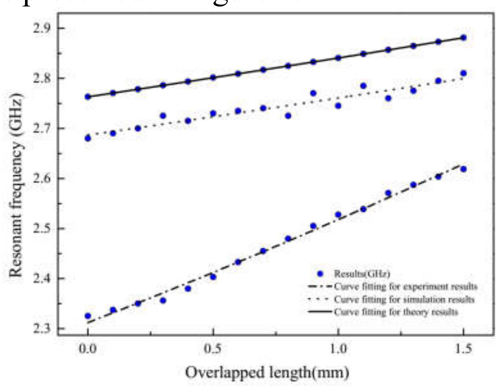


Figure 5. The relationship between resonant frequency and overlapped length in theory calculation, numerical simulation, and in the experiment

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