3D Printed Passive Wireless Strain Measurement

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Passive antenna sensors present an efficient solution for long-term structural health monitoring due to their convenient installation and no external power supply. However, the current fabrication method, chemical etching, is costly and time-consuming. This study investigates the use of extrusion-based additive manufacturing, specifically using polylactic acid, as a cost-effective alternative. Using multi-physics simulations to estimate performance, the results reveal similar strain sensing performance to chemical etching methods, suggesting additive manufacturing could be a promising alternative.

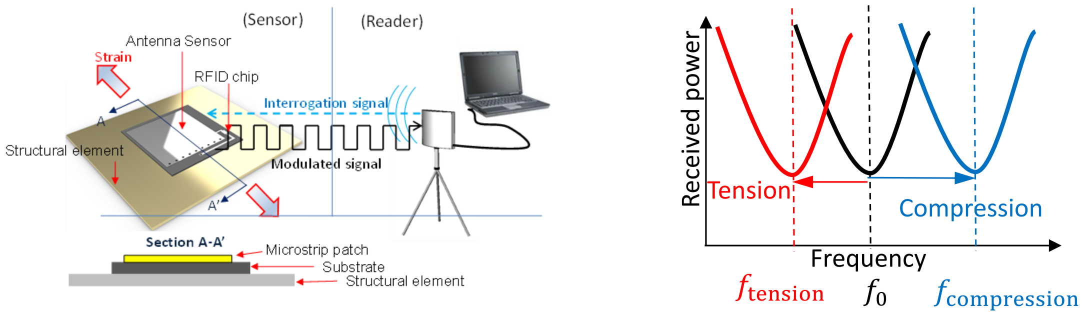
Keywords: 3D printing, Antenna Sensors, Passive Sensing, Structural Health Monitoring, Battery-free

1. Introduction

Structural health monitoring (SHM) involves periodic measurements to ensure an engineered structure's safety [1]. Strain, indicating stress concentration and crack development, is vital. Traditional wireless sensors for SHM are costly due to power and maintenance needs. Passive wireless antenna strain sensors have been developed to mitigate this but their fabrication through chemical etching is expensive and time-consuming [2]. This study proposes additive manufacturing (AM), a layer-by-layer process directed by computer-aided design, as a cost-effective alternative. AM has shown its efficiency and flexibility across various fields, offering the ability to produce functional small quantities at a lower cost.

2.Methodology

The passive communication device used in this study was the Ultra High Frequency (UHF) gen 2 standard, which allows for a broad frequency range of 840 to 960 MHz. This standard utilizes the Tagformance Pro© reader device, which emits an electromagnetic interrogation signal that powers up the receiving antenna sensor, as illustrated in Figure 1.



(a) Schematic of a passive wireless system (b) Strain sensing

Figure 1. Strain sensing mechanism of antenna sensors

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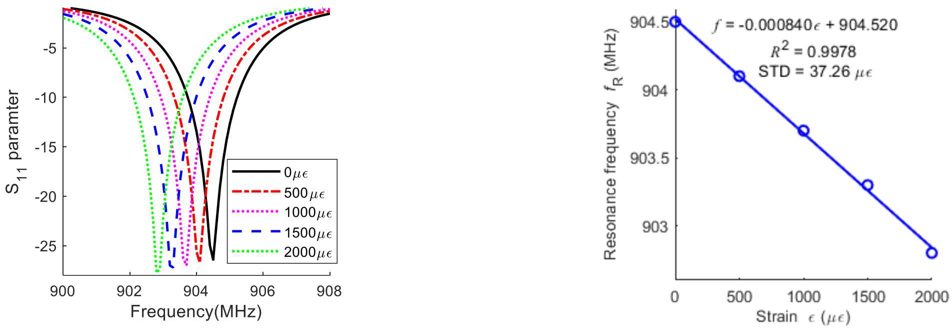
An antenna sensor receives an emitted signal, retaining some power to activate the RFID transponder chip, if sufficient. Once activated, the chip alters the return signal into a backscattered form captured by the reader, encoding strain level data. Based on prior research, the prototype patch antenna was 3D printed using silver nano ink on a PLA substrate. The IMPINJ MONZA R6-P RFID chip was implemented to prevent data collision.

To capture the antenna sensor's electromagnetic response under strain, we utilized coupled multi-physics simulations considering both mechanics and electromagnetics. This involved mechanical simulations for antenna deformation and subsequent electromagnetic response estimation. The strain sensing performances from the simulation is shown in Figure 2. Strain up to 2000με was applied, and scattering parameter (S11) was simulated for each level. Linear regression was performed on minimum S11 values, resulting in a strain sensitivity of -840με/Hz and a coefficient of determination of 0.9978.



(a) S_{11} scattering parameter (b) strain vs frequency plot

Figure 2. Simulation strain sensitivity of the printed sensor

3. Discussion and Conclusion

This study explored 3D printing for antenna sensor fabrication, including detailed mechanical analyses of PLA to determine the elastic modulus versus infill densities, and multi-physics simulation for strain sensing estimates. Results yielded a strain sensitivity of -840με/Hz with a strong linearity coefficient of 0.9978, supporting AM's potential in antenna sensor production. Future work includes nonlinear and fatigue tests for enhanced PLA mechanical understanding, methods to boost nano ink conductivity, and systematic design and 3D printing approaches to optimize strain sensing and wireless interrogation distance.

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