# Intelligent Sensing System for Smart Buildings

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## Abstract

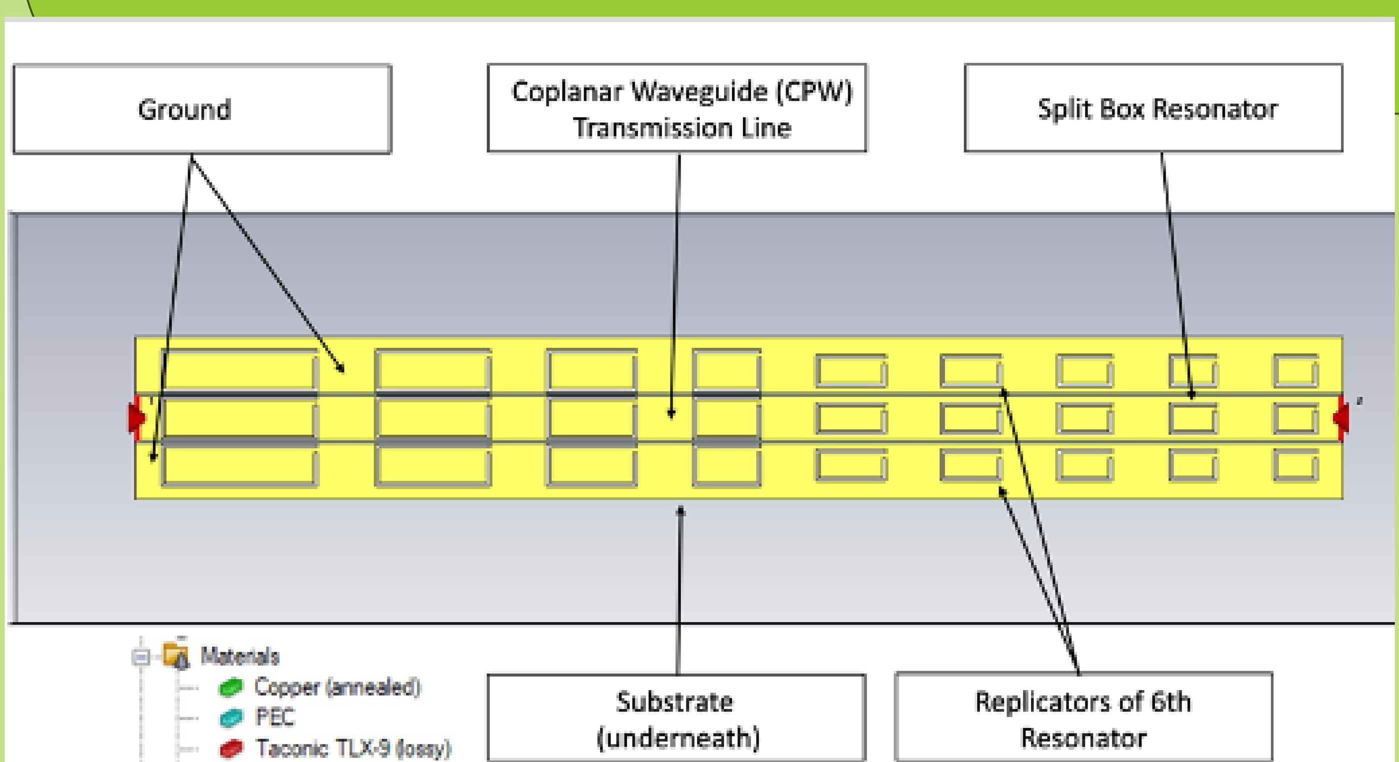
This research project aims to develop a machine learning approach for crack classification in structural health monitoring (SHM). The study focuses on the application of machine learning algorithms to predict the opening and growth of cracks, their location, orientation and dimensions using simulation results obtained from CST Studio Suite. The proposed approach aims to enhance the accuracy of crack detection sensors, specifically RFID-based sensors in SHM systems. The anticipated outcomes include the development of a robust machine learning algorithm capable of accurate crack classification with potential benefits for improved maintenance strategies, enhanced safety, and cost savings in SHM applications.

## Introduction

Smart buildings have become a prominent focus of interest due to their autonomous capabilities in detecting and responding to changes. They function like a nervous system, alerting potential issues and ensuring operational safety. One key approach to achieving this is Structural Health Monitoring (SHM) using Wireless Sensor Networks (WSNs) to monitor factors such as temperature, vibration, and strain. SHM is vital for modern infrastructure, leading to significant annual savings, primarily driven by enhancing safety measures and reducing operational costs. This research aims to improve SHM systems by leveraging machine learning techniques for accurate detection and classification of structural issues. By implementing RFID-based sensors and machine learning, the research aims to streamline the monitoring process, minimize human labor, and reduce long-term operational costs for maintaining infrastructure. RFID technology enables wireless data collection, making it particularly useful for crack detection in SHM.

## Sensor Design

This research focuses on a "smart skin" sensor designed for Structural Health Monitoring (SHM) applications, enabling the detection of cracks, strains, and moisture within building walls. The sensor, based on chipless RFID technology, consists of a sensitive microwave structure with split box resonators integrated into a coplanar waveguide transmission line. These resonators interact with electromagnetic waves in a unique way, allowing for efficient wireless detection when probed with a reader. The sensor's design significantly reduces fabrication costs, making it cost-effective for large-scale implementation in SHM. By analyzing the S-parameter 2.1 measurements, which characterize the sensor's behavior in response to cracks, the research aims to train machine learning algorithms for accurate crack classification, contributing to the development of more efficient and accurate SHM systems.

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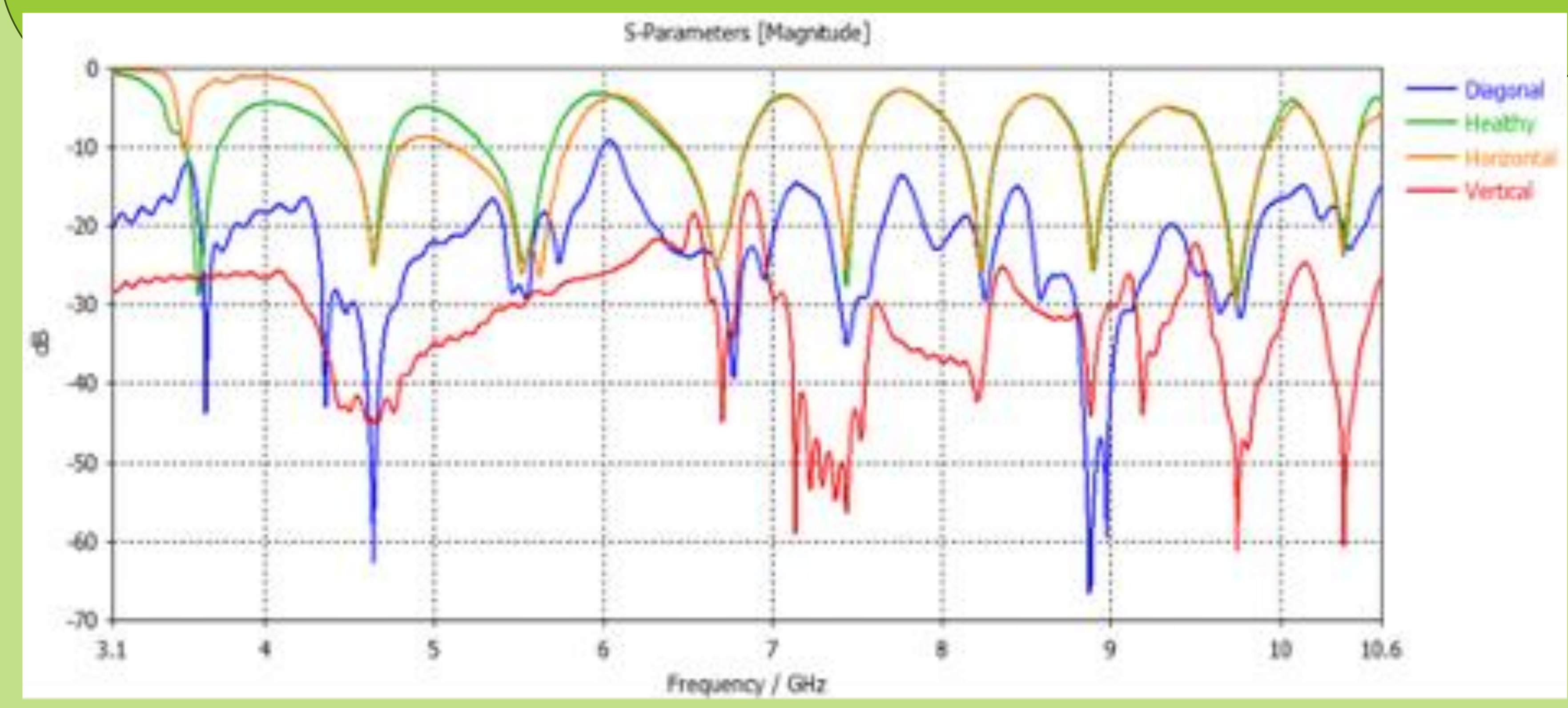
## Classification Justification

In this section a comparison of four simulations is presented. Three of the simulations include different crack scenarios introduced to the sensor while the fourth represents a healthy sensor. All three crack scenarios feature cracks of the same size, differing only in their orientation. The visual representation clearly demonstrates the impact of crack orientation of the S-parameter response. Specifically, the vertical crack exhibits the most significant effect, leading to the most noticeable deviation from the healthy sensor data. On the other hand, the horizontal crack shows the least impact with its backscatter response closely resembling that of the healthy sensor. Interestingly, the diagonal crack demonstrates intermediate behavior, likely due to its 45-degree angle positioning which places it between the vertical and horizontal cases.




## Result and Discussion

This section presents a comparison of results from two experiments on crack orientation classification using machine learning techniques. The first experiment used a small dataset of 300 rows, achieving a commendable test accuracy of 0.8413, while the second experiment with a larger dataset of over 25,000 rows resulted in a slightly lower test accuracy of 0.7597. The difference in performance raises insights into the relationship between dataset size and model accuracy, with possible explanations being overfitting in the smaller dataset, leading to a more focused model, and the larger dataset introducing complexities and noise, making generalization challenging. The investigation into the confusion matrix and classification reports also revealed patterns, with the smaller dataset model performing better in classifying "V" and "D" orientations, while the larger dataset model showed higher accuracy for the "H" orientation, likely due to the differing sample sizes for each orientation in the datasets. Fine-tuning the model based on the role of overfitting will be crucial for future work.

| | Accuracy | Loss |
|---|---|---|
| **300 Rows** | 0.8413 | 0.5520 |
| **>2,500 Rows** | 0.7597 | 0.6152 |

## Future Work

In the future work phase of the project, several directions are suggested to enhance the machine learning system for crack classification in Structural Health Monitoring (SHM). One key task is to develop a comprehensive machine learning system capable of predicting the precise dimensions of cracks using the S2.1 graph, shifting from multi-class classification to a regression approach. This would provide engineers and maintenance personnel with more detailed information for making informed decisions about structural repairs and maintenance. Expanding the dataset by collecting additional data with unique and unseen crack locations and sizes is crucial to train more accurate and robust machine learning models, improving their generalization capabilities. Another area of exploration involves investigating the model's ability to predict the number of cracks present by introducing multiple cracks to the sensor, formulating it as a multi-label classification problem. Future work could also extend the system to accurately predict the locations of all detected cracks and their corresponding dimensions using localization and regression techniques, aiding in targeted repair and maintenance efforts. These advancements in future work will enhance the effectiveness of SHM and contribute to the advancement of the field, ensuring the safety and longevity of critical infrastructure.