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Smart Super Hydrophobic Textiles Utilizing Long-Range Antenna Sensor for Hazardous Aqueous Droplet Detection and Prevention

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ABSTRACT

This review paper explores the integration of smart superhydrophobic textiles and antenna sensors for detecting and preventing hazardous aqueous droplets. Superhydrophobic surfaces have gained attention for their water-repellent properties, and advancements in fabrication techniques have enabled the creation of superhydrophobic textiles that effectively repel liquid droplets. To enhance functionality, antenna sensors are incorporated into the fabric structure, allowing real-time detection of toxic chemicals, pathogens, and other contaminants present in aqueous droplets. The integration of antenna sensors with superhydrophobic textiles presents a synergistic approach to addressing challenges in detection and prevention in healthcare, industrial safety, and environmental monitoring. The review covers recent advancements in materials, fabrication techniques, and water-repellent mechanisms of superhydrophobic textiles, as well as the integration strategies for sensor implementation. It also discusses potential applications, limitations, and future prospects. The findings emphasize the promising opportunities for these technologies in improving safety measures, monitoring capabilities, and rapid response mechanisms across various industries. Overall, the integration of smart superhydrophobic textiles and antenna sensors holds great potential for revolutionizing the detection and prevention of hazardous aqueous droplets.

Keywords—Hydrophobic, Antenna Sensor, Planar Antenna Sensor, Patch Antenna Sensor.

1. Introduction

The emergence of advanced materials and technologies has revolutionized various fields, including healthcare, environmental monitoring, and industrial safety. Among these materials, superhydrophobic surfaces have gained significant attention for their exceptional water-repellent properties, making them ideal for applications where liquid repellence is crucial. In recent years, the integration of superhydrophobic textiles with antenna sensors has opened new avenues for detecting and preventing hazardous aqueous droplets, such as toxic chemicals, pathogens, and other contaminants.[1][10]

The combination of superhydrophobic textiles and antenna sensors offers a synergistic approach to addressing challenges in the detection and prevention of hazardous aqueous droplets.[4] Superhydrophobic textiles prevent the adsorption of liquid droplets, while antenna sensors enable real-time monitoring of the presence of contaminants in the droplets.[3] The integration of these technologies has potential applications in various fields, including healthcare, where the rapid detection of infectious agents is crucial for disease control, industrial safety, where exposure to toxic chemicals is a significant concern, and environmental monitoring, where water contamination is a persistent issue.[5]

This review paper provides an in-depth analysis of recent advancements in smart superhydrophobic textiles and antenna sensors for detecting and preventing hazardous aqueous droplets. It covers the materials and fabrication techniques employed in the development of superhydrophobic textiles, their water-repellent mechanisms, and the integration strategies for sensor implementation. Furthermore, it explores potential applications of these technologies in various industries and discusses their advantages, limitations, and prospects.

2. Methodology

2.1 Preparation of Hydrophobic Textiles

The process of creating hydrophobic cotton textile involved several steps. Firstly, the textile was soaked in a 0.5 wt.% ethanol solution of amino-functionalized SiO2, followed by passing it through a two-roll laboratory padder to achieve a wet pick-up of 70-80%. This process was repeated twice before curing the textile at 110◦C for an hour. Secondly, the amino-functionalized SiO2-coated textile was further treated by substituting it with epoxy-functionalized SiO2, using the same method. [6] To make the textiles hydrophobic, stearic acid and PFTDS were used alone or in combination. Treatment with stearic acid involved immersing the textiles in a solution of stearic acid, followed by padding and curing. Similarly, the treatment with PFTDS was done by immersing the textiles in a PFTDS solution of toluene, followed by drying. For combination treatment, the samples were treated with stearic acid first, followed by PFTDS.[6]

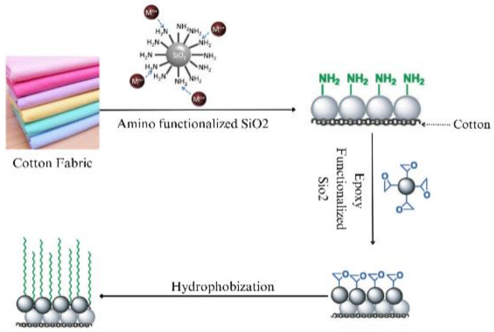

Fig 1. Preparation of Hydrophobic Textile using amino functionalized SiO2

2.2 Preparation of Hydrophobic Textiles by SOL GEL Method

Cotton fabric was extensively washed with ethanol, added dopamine hydrochloride and 80 mL of Tris-HCl solution, and agitated under ultrasonic for 10 minutes. DTMS solution was applied, switched for 4 hours, and vacuum-dried at 60 °C. Supplies were A. Tetraethyl orthosilicate, ammonia water, heptadecafluoro-1,1,2,2-tetrahydrodecyl triethoxysilane, ammonium persulfate, ethanol, and methanol. Microwave structures were created on a Rogers RT/duroid 5880 substrate.

Superhydrophobic fabrics were produced by dip-coating using a two-step procedure, treated with low-energy surface fluoro silane. Methanol and deionized water are mixed in a ratio of 70:30, dissolved in TEOS, heated to 40 °C, and ammonium hydroxide mixed to the mixture. Four distinct perfluorinated Methanol solutions are made with silane at concentrations of 0.5, 1, 2, and 4 weight percent, applied to fabrics for 10 minutes at 25 °C and baked for 10 minutes at 180 °C.[2]

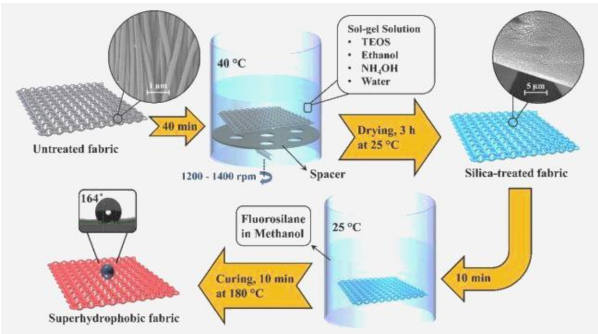

Fig 2. Preparation of Hydrophobic Textile using SOL-GEL Solution [2]

2.3 Patch Antenna Sensor

Antennas are designed using MATLAB Software with Antenna Designer toolbox. By selecting Microstrip Patch Antenna and setting the frequency to 3.11G Hz. The pattern, S-Parameter, Directivity, Impedance etc, can be analysed. S-Parameter output Fig. 3 Patch antennas are Specifically utilized at Low Frequencies.[8]

The patch Antenna Sensor has wide range of applications in Volatile Organic Compounds, Toxic Gases, Corrosive Chemicals, Explosive or Flammable Gases like methane (CH_4), propane (C_3H_8), or hydrogen (H_2), Biological and Chemical Warfare Agents, & Environmental Pollutants.[9]

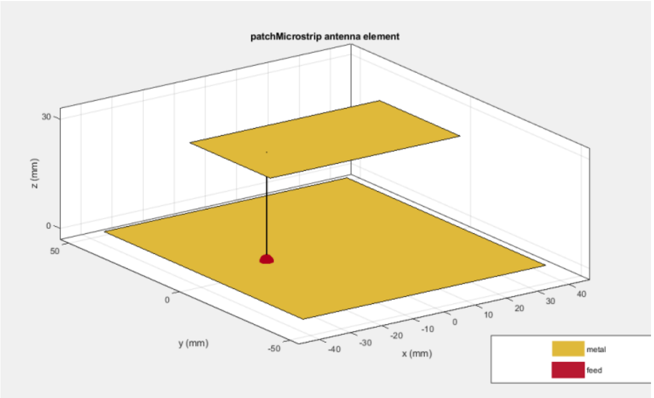

Fig 3. Design of Patch Antenna in MATLAB

2.4 Planar Antenna Sensor

Antennas are designed using MATLAB Software with Antenna Designer toolbox. By selecting Inverted hco Planar Antenna and setting the frequency to 3.11G Hz. The pattern, S-Parameter, Directivity, Impedance etc, can be analysed. S-Parameter output Fig: 5 Planar antennas have High Frequency band.[7]

The Planar Antenna Sensor has Wide Range of Applications similar to as Patch antenna

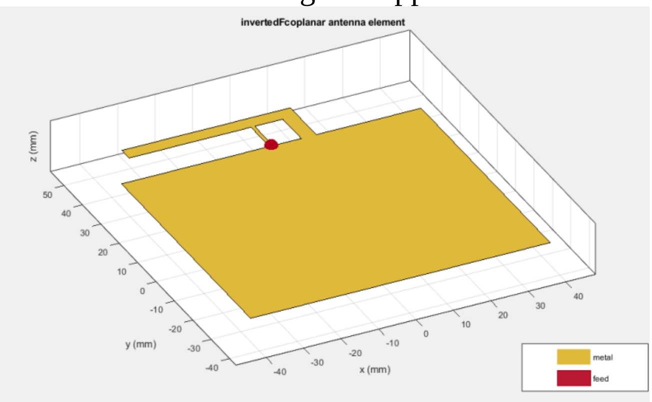

Fig 4. Design of Planar Antenna in MATLAB

3. Results and Discussion

3.1 Comparison Between Patch Antenna Sensor and Planar Antenna Sensor

Planar antenna sensors and patch antenna sensors are two types of antennas commonly used in sensor applications.

Design and Structure:

Both planar antenna sensors and patch antenna sensors are types of planar antennas. Planar antenna sensors are thin, flat structures with conductive elements printed on a dielectric substrate. They can have different shapes and the conductive elements are interconnected. Patch antenna sensors, on the other hand, are a specific type of planar antenna.[10] They consist of a rectangular or circular conductive patch on a dielectric substrate and are fed by a transmission line like a microstrip line. Both types of antennas are used in sensor applications, with planar antennas offering more shape options and patch antennas being a specific design within the planar antenna category.

Radiation Pattern:
Planar antenna sensors exhibit varied radiation patterns based on their design and feeding mechanism, allowing for both broad and narrow beamwidths to suit specific application requirements. Patch antenna sensors, on the other hand, generally have a broad, fan-shaped radiation pattern. The shape of the patch and the ground plane beneath it influence the radiation pattern, enabling patch antennas to radiate in a particular direction with a relatively wide beamwidth.[12]
Frequency Range:
Planar antenna sensors have a wide frequency range, spanning from low frequencies (a few MHz) to microwave and millimeter-wave frequencies.[11] They are versatile in their frequency capabilities. In contrast, patch antenna sensors are specifically utilized in higher frequency ranges, predominantly in the microwave and millimeter-wave frequencies.[13] They are particularly suitable for applications such as satellite communication, wireless communication systems, and radar.
Size and Compactness:
Both planar antenna sensors and patch antenna sensors offer compact and low-profile designs, making them ideal for integration into small devices or systems. Planar antennas are commonly used in applications with size and weight constraints, while patch antennas are specifically known for their compact size and low profile.[14] Patch antennas find applications in a range of devices, including mobile phones, RFID tags, and wireless sensor nodes.
Manufacturing and Cost:
Both planar antenna sensors and patch antenna sensors can be manufactured using printed circuit board (PCB) fabrication techniques, which are cost-effective for mass production. The manufacturing cost of both types of antennas is generally reasonable and affordable.[15] PCB manufacturing techniques offer an efficient and cost-efficient means of producing planar and patch antennas in large quantities.

3.2 Planar Antenna and Patch Antenna

Patch Antenna:

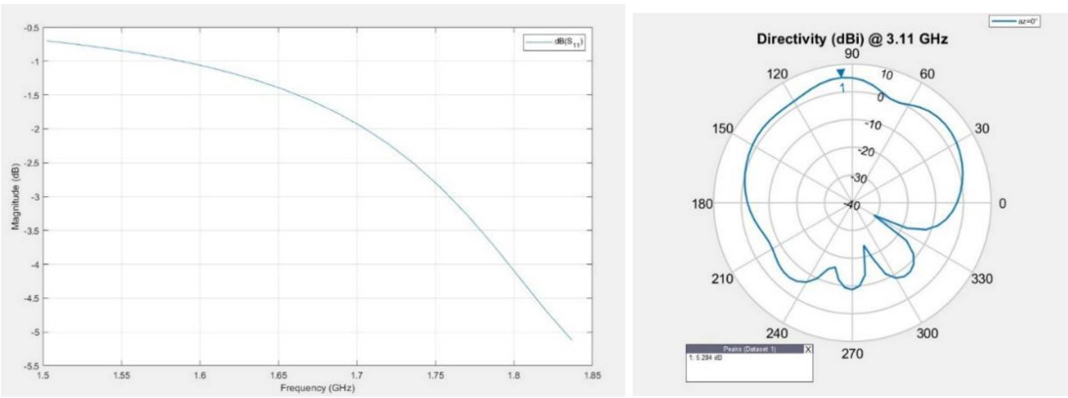

Fig 5. S-Parameter Analysis and Directivity for Patch Antenna

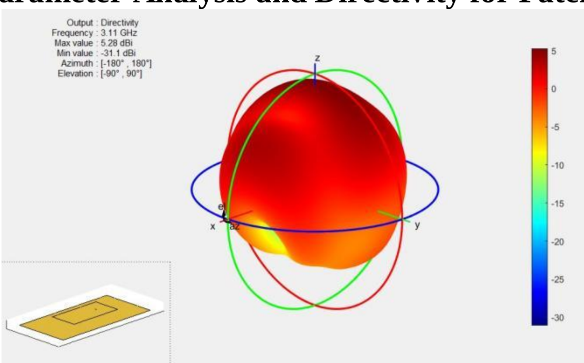

Fig 6. Pattern Analysis of Patch Antenna sensor

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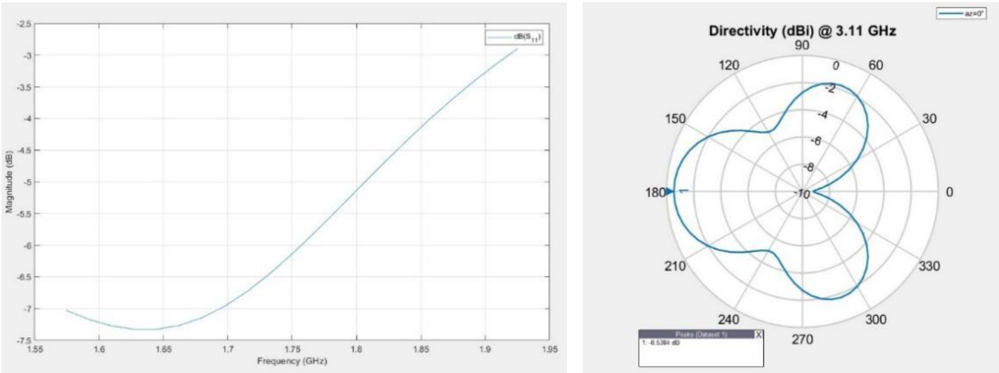

Fig 7. S-Parameter and Directivity of Planar Sensor

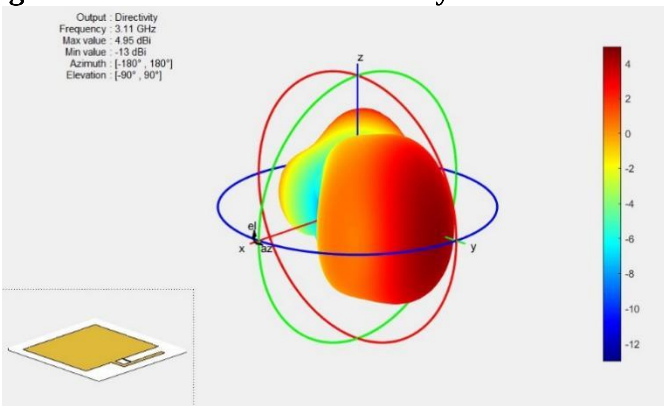

Fig 8. Pattern of Planar Antenna Sensor

Table.1. Comparison Between Patch Antenna & Planar Antenna

Parameter	Patch Antenna	Planar Antenna
Operating Frequency	3.11G Hz	3.11G Hz
Max Value	5.28dBi	4.95dBi
Min Value	-31.1dBi	-15dBi
Azimuth	[-180, 180]	[-180, 180]
Elevation	[-90,90]	[-90,90]
Frequency Range	Low Frequency Range	High Frequency Range
Directivity	1: 5.284 dB	1: -0.5384 dB

Table.2. Comparison Between Methods of preparation of Super Hydrophobic Fabric

Parameter	Method 2.1	Method 2.2
Coating Material	Amino-functionalized SiO2 and epoxy-functionalized SiO2	Tetraethyl orthosilicate (TEOS), ammonia water, and heptadecafluoro-1,1,2,2-tetrahydrodecyl triethoxysilane
Treatment Agent	Stearic acid and perfluorooctyltrichlorosilane (PFTDS)	Low-energy surface fluoro silane solutions with different concentrations of

		perfluorinated methanol
Application Process	Soaking the textile, two-roll laboratory padder, curing	Washing the fabric, application of dopamine hydrochloride and Tris-HCl solution, dip-coating
Curing/Drying Conditions	Curing at 110°C for an hour	Vacuum-drying at 60°C, baking at 180°C

CONCLUSION

The choice of the best antenna depends on specific requirements and priorities. The Patch Antenna offers higher maximum gain, but the Planar Antenna performs better in terms of minimum gain and directivity. The Patch Antenna is designed for the low-frequency range, while the Planar Antenna is designed for the high-frequency range. Consideration of factors such as gain, directivity, frequency range, and other application requirements is essential in determining the most suitable antenna for a particular use case. Method 2.2 involves the use of low-energy surface fluoro silane solutions with different concentrations of perfluorinated methanol as treatment agents. The combination of TEOS, ammonia water, and heptadecafluoro-1,1,2,2-tetrahydrodecyl triethoxysilane as coating materials also indicates an emphasis on enhancing hydrophobic characteristics. However, achieving 98% hydrophobicity depends on various factors such as the specific textile material, the application method, and the overall process parameters. Further tests and optimizations will help determine the best method for achieving the desired level of hydrophobicity.

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