A Review on Microstrip Patch Antenna Sensors: Agriculture, Environment, Health Care and IoT Applications

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Abstract: - As the quantity and needs of advanced wireless communication systems have grown, the latest advancements in antenna sensors that support them have also enhanced. This review paper describes numerous microstrip patch antenna sensors utilized in various applications such as agriculture, the environment, biomedical, and the Internet of Things. The survey provides the several issues that come with constructing microwave sensors utilizing various simulation software, material selection, and manufacturing procedures. This paper summarizes the sensors and their categorization, as well as printable antenna sensors, issues that arise in antenna sensor design, antenna sensor layout, and kinds, and their applicability in various fields. These antenna sensors have received much attention in current history because of their appealing qualities and potential for allowing lighter, adaptable, low-cost, tiny size, patient safety, communication capability, biocompatibility, and portable wireless communication and sensing.

Key-Words: - Microwave sensors, Printed antenna sensors, Microstrip patch antenna sensors, Internet of things (IoT), Temperature sensor, Health care application, Moisture sensor, Wireless communication.

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1 Introduction

Sensors are increasingly engaged in practically every aspect of life since they provide instantaneous feedback on the environment around us, similar to our own five senses of taste, sight, hearing, touch, and smell. The most recent science and technology are used in modern sensors, and innovative sensors made of biomolecules, nanostructures, and Nanoelectronics are produced. Sensors are rapidly approaching the point where they will be able to detect illnesses, detect danger, prepare our food, recognize terrorists, assist in the capture of fugitives, reduce pollution, and provide clean and effective temperature controls for human safety and comfort in our automobiles, offices, and homes. Overall, developments in sensor technology should make the world a better place. Sensors have become smaller in size due to technological advances and can be used for a variety of human activities, [1], [2]. Sensors for measuring structural reactions and operating conditions like strain, pressure, crack, stress, pH, moisture content, humidity, temperature, and so on have been created, [3]. Conventional methods for large-scale sensor network deployment include running long cables to provide power and collect data from individual sensors, or installing integrated transceiver sensors without powering batteries, which eliminates the need for wiring but poses long-term environmental risks from the disposal of billions of batteries. However, these technologies are necessary in some cases where real-time data is required, [4]. While the adoption of WSNs has decreased wire costs, these systems have their flaws, such as those related to time synchronization and dependability. WSNs, on the other hand, have a basic energy restriction. The energy required for sensing data is a major problem due to the restricted capacity of non-rechargeable batteries used in WSNs. To address this problem, energy harvesting, or the conversion of mechanical energy to electrical energy, has been proposed. Energy harvesting devices have gotten a lot of interest as a way to increase the lifetime of WSNs and solve the energy limitation problem, [5].

Wireless sensor networks (WSNs) are less costly and simple to implement than traditional sensors since they do not require electric wiring, allowing us to collect huge volumes of data that can considerably increase our understanding of the environment. This approach allows for the distribution of sensors across a vast region and at a high density. However, to large-scale widespread sensor networks that capture a massive amount of data, the detection system must be reliable, eco-friendly, and relatively cheap, [6]. Antennas were traditionally been utilized exclusively as a means of communication for sensing devices. However, recent improvements have expanded the sensing role of antennas. Using the idea of antenna backscattering, an antenna sensor may be wirelessly evaluated at intermediate-range areas with no need for a built-in battery, [7]. These antenna-based sensors are unusual in that they can both sense and communicate. It is feasible to extend the range and area of sensing by using wireless sensor networking, [8]. Antennas function as transducers, converting electromagnetic waves into radio signals and vice versa. Furthermore, remotely sensed data or sensing systems would be impossible to imagine without antennas, and radio wave dispersion in complicated surroundings is a critical part of these systems' functionality. Emerging technologies like 5G open up new possibilities for sensor networks while also posing new antenna design issues, [9].

Electronic devices employ passive antennas to transport data between a user and a network, or the devices communicate data with one another without the user's interaction, as machine-to-machine technology. Such passive antennas may be found in a wide range of electrical equipment, particularly portable ones. Any passive antenna can be manufactured from a variety of electronically conducting materials in general. Microstrip antennas are now commonly utilized. Copper strips, copper foils, and coatings on various surfaces, such as the well-known FR4 substrate or ceramic surfaces, are commonly utilized for these antennas, [10]. Because of their flat construction and ability to be installed on non-uniform surfaces, patch antennas have had a huge influence on communication systems. To increase the flexibility of patch antennas, researchers are now focused on durable, efficient, and cost-effective manufacturing methods to improve mass production and lower antenna costs, [11]. Thus both planar and non-planar surfaces are suitable with microstrip patch antenna sensors.

In Section 2, we will go through the sensors and their classification following the different characteristic properties they exhibit. Printed antenna sensors, various issues and challenges in the designing of antenna sensors, and the structure and types of antenna sensors are described in section 3. Section 4 summarizes the applications and surveys of antenna sensors in the agriculture, environmental, biomedical, and IoT fields. Finally, the conclusion is presented in section 5.

2 Sensors and Their Classification

Sensors are devices that can detect physical characteristics and turn them into visible signals. A wireless sensing device typically has three functional modules: a sensory interface (which transforms analog sensor inputs to digital data), a computational core (which stores and processes data), and a wireless transmitter (digital communication with peers or a wireless gateway server), [3]. Sensors have often been used to obtain information about the external environment by converting information from one kind of energy to the other. A sensor, in other words, is a device that detects and measures a certain attribute, as well as records or responds to the information received. Sensors may be found everywhere. Sensors are used in daily lives for everything from obtaining weather data to recognizing pollution levels, from analyzing information on the human body and notifying physicians about patients' aberrant health problems to updating mobile users about their cell phone battery levels, [12]. Figure 1 depicts the essential phases of a sensor system. First, we provide the sensory unit with a command. The measured quantity is output after evaluating the input and converting it to an analog or digital signal using an A/D processor.

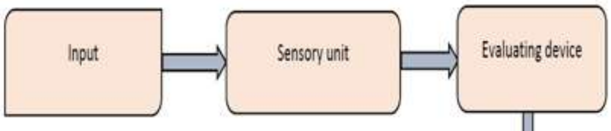

Fig. 1: Basic steps in sensor system, [13]

2.1 Sensors Classification

Sensors are divided into different groups. The most common basic type of classification is given by:

1. Active or Passive Sensors: Active sensors, such as thermistors, mics, straining gauges, and inductive and capacitive sensors, require an external power supply to function. Parametric sensors are the name for these sensors as output depends on the parameter. Thermocouples, piezoelectric sensors,

and photodiodes are examples of passive sensors that generate signals without requiring external energy. These sensors are known as self-generating sensors.

2. Analog or Digital Sensors: An analog sensor converts a physical amount measured into an analog representation (continuous in time). This category of analog sensors includes resistance temperature detectors, straining gauges, and thermocouples. A digital sensor creates a pulse as its output. The digital sensor category includes encoders, [14].

2.2 Sensors Can also be Classified into a Variety of Categories based on Their Characteristics:

As illustrated in Figure 2, these are the types of sensors categorized according to their different characteristic properties like physical, material, functional, detection, conversion area of application, etc.

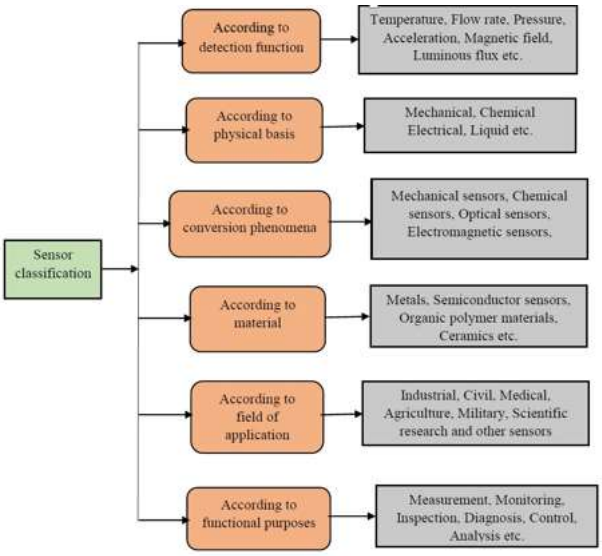

Fig. 2: Sensors classification according to their characteristics, [15]

3 Printed Antenna Sensors

Antenna sensors have received a lot of interest in recent years because of their passive wireless function, easy design, multiplex abilities, tiny size, and multi-modality sensibility. Since the antenna does both sensing and communication, the antennae sensors may be constructed with few components, [7]. Antennas are the equipment that transform radio frequency transmissions into electromagnetic wave signals. Aperture antennas, reflector antennas, lens antennas, patch antennas, and printed antennas are examples of these antennas. A microstrip antenna is the most basic and sophisticated type of printed antenna. Microstrip patch antennas are now the most prevalent form of microstrip antenna due to their small size, low weight, inexpensive, planar structure, low profile, and superior portability, [16]. These antennas come in a variety of forms, including triangular, round, rectangular, elliptical, etc., [17], [18]. The smart sensor system must be self-contained in terms of sensing, processing, and data delivery for a variety of applications. Fortunately, as personal communication systems such as Wi-Fi and WiMAX have advanced, a growing variety of antennas with various architectures and functions have been produced. Printed antennas, for example, offer several benefits that make them the ideal choice in cellular communication and wirelessly sensing applications like smart technology sensors and wireless sensor systems, [19]. Printed antennas have shown that they may be used in sensing as well as in energy collecting in addition to communicating, [20]. Sensor demand has increased as industrial processes have become more automated. Various types of microwave sensors have overcome many of the new measuring challenges. As a result, microwave sensors are becoming increasingly widespread in many industries. The interaction between microwaves with matter is the basis for microwave sensors. Reflection, refraction, scattering, emission, absorption, or changes in speed and phase are all examples of interactions. Microwave sensors are utilized for a broad range of applications, including distance measurement, movement, form, and particle size measurement, but the most common use is material property monitoring, [21].

3.1 Challenges and Issues in Designing Antenna Sensors

Reduced size, improved directivity, gain enhancement, bandwidth widening, and back lobe or side lobe suppression are all aspects to consider while building a patch antenna. The main problem stems from a balance between sensing and network communication, namely between reading distance, precision, compactness, responsivity, and resilience. This tradeoff and other significant problems impact the antennae types, substrate material in the label, monitoring principle, choice of detecting parameters in the device, deployment of test methods, and construction of the feature-based approach, [6], [22]. Selecting a substrate material with a particular dielectric constant that does not vary under any situation is among the most important parts of antenna design. Even modest alterations in patch patterns have an impact on the fringing fields at the edges. The effective length is changed, which alters the resonance frequency, [23].

The main drawbacks of patch antennas are their limited bandwidth and low gain. Getting the proper resonance frequency is one of the challenges in building the microstrip patch antenna. The antenna resonates at the proper frequency when the length and breadth of the patch are chosen correctly, [24]. Some more challenges of designing an efficient antenna include selecting the right antenna for the right application from thousands of available designs, being highly compact, having good performance efficiency, and contributing to lower power consumption and better data rates while maintaining a good transmission range, [25].

3.2 Structure and Types of Antenna Sensors

As shown in Figure 3, a microstrip patch antenna is made up of three parts: a ground plane, a substrate, and a radiating patch. A dielectric substrate of height h separates the conducting ground plane and the radiating patch, forming an electromagnetic resonant that emits specific radiating patterns, [26].

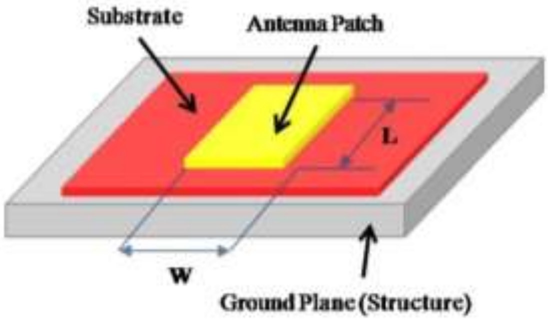

Fig. 3: Fundamental design of Microstrip patch antenna, [27]

Antenna sensors are divided into several groups. Dielectric sensor, implantable sensor, temperature sensor, mechanical sensor, resonator sensor, and crack sensor as mentioned in Figure 4 (Appendix), are the six basic types of antennae sensors, [28].

4 Applications of Antenna Sensors

Antenna sensors have been utilized in a range of applications, such as agriculture, the environment, health care, structural health monitoring, food quality monitoring, the Internet of Things, and so on. Through the interplay of dielectric characteristics and electromagnetic waves, patch antennas operate as sensors, [28].

4.1 Survey of Antennas for Agriculture Application

In the agriculture field, sensors have been utilized to help with (1) spatial data gathering, (2) precision irrigation, (3) varying technology, and (4) data transfer to farmers. In the system, wireless sensors are employed to facilitate irrigation scheduling by combining on-site meteorological data, remotely sensed data, and farmer requirements.Sensors have also been used in the food industry in recent times to control and maintain the quality features of food items, [29], [30]. A circular ring wireless microstrip moisture sensor for detecting the moisture level in meals, soils, fruits, maize, grains, and packed packets have been designed. Due to the FR4 substrate, the sensor would be low-cost and function in the distant field without the need for a battery. This wireless microstrip moisture sensor is based on backscatter characteristics and can also detect distilled water with the help of backscatter characteristics, [31].

A circular microstrip resonator sensor with a slotted ground plane helpful for detecting moisture content in grains has been developed. This sensor introduced for the agriculture field will be low cost, small measurement setup, and be easy to install, [32]. To measure the moisture level of soil samples, single-band and dual-band resonant frequency antennas have been presented. The broad coverage of a dual resonant frequency antenna allows it to be used in a variety of applications. For better results, rectangular microstrip antennas are created and modified with various slots, [33]. A microstrip humidity sensor with a reduced average relative error was developed to determine the moisture level in rice. The sensor is small and inexpensive. Because there is an immediate fluctuation in the reflection coefficient, the sensor would be able to identify even minute amounts of water or humidity in rice, [34].

A microstrip patch antenna-based U-shaped moisture sensor with simple approach, low cost, and compact sensor size, was designed. The suggested device beats existing dual-frequency designs, [35]. Because of its ease of feeding and minimal false feed radiation an antenna having a defective ground structure with a microstrip feed line was constructed. It determines how much moisture is in grains. This approach is easier to use, takes less time, and is more accurate than the others, [36]. To identify rice quality, an H-shaped patch sensor coaxial line feed is used and the moisture is measured using the oven drying method, [37]. For rice grain wetness monitoring, a rectangular microstrip sensor was presented.

The detector is of low insertion and relies on an oven-drying technology that is simple, quick, and time-saving compared to other methods, [38]. A microwave sensor was used that is small, lightweight, strong, and extremely sensitive to measure the moisture content of the soil. It is based on the idea that the dielectric constant increases with increasing moisture levels, [39]. A circular patch sensor was proposed to measure the moisture content of rice grains based on the oven-drying process. The microstrip's feeding port will be a 50 ohm SMA female connector for fabricating, [40]. A rectangular microstrip antenna sensor was developed using the microstrip transmission feeding method to determine soil suitability for agricultural applications. This small-sized, inexpensive device may be used to instantly ascertain the microwave properties of farmland, [41].

A patch antenna was proposed with coaxial probe feeding for the evaluation of soil moisture content. There are two ways to identify wet spots in soil: one is by employing a transmission-technology-based probe scanner, and the other is by inserting sensor antennas into the soil. Both methods rely on the soil's topmost surface to determine whether the soil is damp or wet, [42]. A microstrip moisture sensor with a compact footprint, an easy-to-use design, a low cost, and a high response quality was designed and can be used to measure soil moisture. To increase accuracy in the shortest amount of time, the design is modified. The patch has four slots in this design, [43]. A set of comparable patch antennas were suggested with coaxial probe feeding for figuring out the inherent moisture content of soil samples using Topp's equation.

In the middle, a slab holder holds the samples of soil whose dielectric characteristics should be evaluated. The experiment is carried out at three different frequencies, and for every sample dielectric constant has to be calculated, [44]. For the measurement and analysis of soil and pests to reduce the amount of fertilizers and minerals added to soil at specific places and times, a sensitive and easy sensor has been designed. The first patched sensor had a single frequency response, but the second patched sensor was modified to have dual resonating frequencies, [45]. A single layered and stacking patch antenna for simultaneous measuring of the moisture in the soil and communications was proposed. The sensor band is meant to be as sensitive to moisture as possible, whereas the communicating band is constructed to be as resistant to variations in soil wetness as possible, [46]. An example of a microstrip patch antenna moisture sensor has been shown in Figure 5 and Table 1 (Appendix) gives the analysis of various antenna sensors used in the agricultural field.

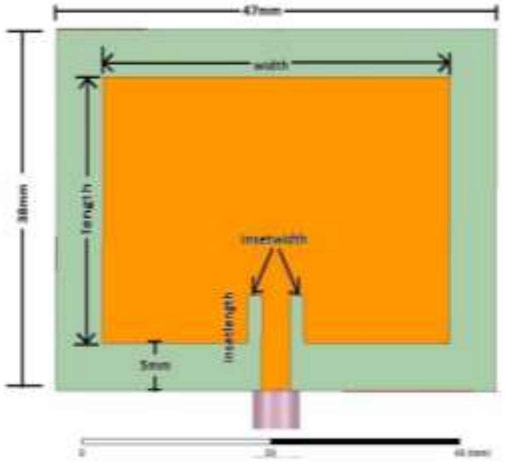

Fig. 5: Microstrip patch antenna moisture sensor, [47]

4.2 Survey of Antennas for Environment Application

Traditional wired measures can cause electric sparking and can't be utilized safely in restricted spaces, which limits their usage in adverse environments. In these instances, wirelessly and passively measurements have shown to be a safe and effective way of parameter collection. Antenna embedded sensor is a revolutionary device that can analyze parameters wirelessly in tough settings. It miniaturizes the monitoring device by integrating the responsive element into the antenna's substrate, and it detects the surrounding environment via the antenna's resonance frequency variation, [48].

A dual-frequency antenna sensor was created using the PCB manufacturing method. Thermal cycling of patched antennas on various metal substrates is used to examine temperature sensing. The observed antenna frequency resonance shifts are investigated using thermocouple readings. By assessing the influence of temperature on the resonant frequency of the antenna, the proposed microstrip antenna acts like a temperature sensor. It would be low-cost to manufacture and can even be examined wirelessly over great distances, [49]. To measure temperature without using electronics, a distant field investigation of a microstrip antenna was used. The temperature-detecting element is a patch antenna, whereas the transmitter and receiver are an ultra-wide-band antenna on the sensor node, [50]. Microwave antenna for moisture content detection was created and investigated. The suggested patch antenna acts like a sensor since the specimen has varied dielectric permittivity based on water level and will have various resonance frequencies. Due to its high sensitivity, compact size, and changeable frequency shift, it may be employed as a moisture content as well as other liquid identification sensor, [51].

A wirelessly passive temperature detection system based on a PCB was developed, built, and tested. The sensor's capacity to sense lower and higher temperatures ranging from 40 to 125 degrees Celsius was evaluated. The sensor has various benefits, including minimal cost, ease of integration, easy processing, and a basic mechanical design, [52]. A double-frequency microstrip antenna sensor having a 50-ohm microstrip transmission line supplied at the radiation patch's border is proposed. The antenna device was tested on copper, steel, and aluminum. It's crucial for manufacturing operations, structural safety, and environmental monitoring, [53].

A temperature-sensing reconfigurable sensor antenna with a slotted patched structure is suggested. It's made up of an antenna, a sensor, and a built-in chip (IC). The sensor converted the input from the environment into an electric component. The antenna absorbs and distributes electromagnetic radiation in space under the control of this component, [54]. The use of an InSb microwave antenna to create a THz temperature sensor was studied. The sensor's equivalent circuit was constructed via particle swarm optimization at various operating temperatures using a five-lumped element concept.

The performance of the sensor affected by the temperature of the surroundings is explored. It may change the characteristic impedance bandwidth, beam direction, wave polarity, and frequency response to adapt to different sensor conditions. In a hostile environment, the suggested design may detect large temperature variations, [55]. A passively operated wireless sensor having a high temperature is manufactured, based on an AlN ceramic type patch antenna, and fabricated by using thick film technology. An interrogating antenna and temperature sensor are included. The sensor is small, low-cost, has a basic construction, is easy to integrate, can operate at high temperatures, and is simple to manufacture. It can withstand high temperatures, chemically corrosive environments, and other extreme conditions, [56]. A print-etching-fabricated microwave antenna was presented for simultaneous superstrate monitoring and sensing of temperature. The antenna design is first produced on a transferring paper film, then printed to a PCB with the use of the heat source. It may be used to measure the dielectric properties and thickness of various materials with temperature compensation. At the same time it can sense temperature within a boiler and ash deposition, [57]. A patch antenna was created with having feed inset and Nanocomposite as a patch layer. It can be used as a passive wireless temperature sensor.

The proposed microstrip patch antenna acts as a highly robust, low-cost, and highly sensitive passive wireless temperature sensor for advanced flexible organic purposes and medical applications. The microstrip patch antenna designed by using Nano composites showed excellent sensitivity to temperature as compared to the copper MPA, [58]. A pH sensor using a plane microstrip antenna was constructed. To attain the minimum reflection coefficient and necessary bandwidth many simulations were run. The fabrication method employs standard PCB processing and etching procedures. Because of its easy operation, reusability, and sensitivity to minor pH changes, it is a strong option for online pH monitoring applications.

Due to the monitoring and regulation of the pH level of water, meal, soil, and other beverages, is significant for a wide range of applications such as environmental, agricultural, biological sensing, food quality checking, and structural health monitoring, [59].

For the measurement of salt and sugar content, a microwave sensor was used. The ground having slots is etched over one side of the material. The reflection coefficient is used to determine sugar and salt content. As the proportion of salt and sugar increases, the dielectric constant decreases, and the reflection coefficient decreases. It may be used in industry to determine the amount of sugar and salt in beverage products and foods, [60]. A Microwave sensing device for sugar and salt determination in water was developed. Because varying amounts of sugar and salt in water have variable dielectric characteristics, hence Q-factor and reflection coefficient alter. It creates a low-cost setting for food production operators, authorities, and consumers to determine the amount of sugar and salt in food or beverage, [61]. Here Figure 6 represents the example of a temperature sensor patch antenna, and the survey of antenna sensors for environmental application is illustrated in Table 2 (Appendix).

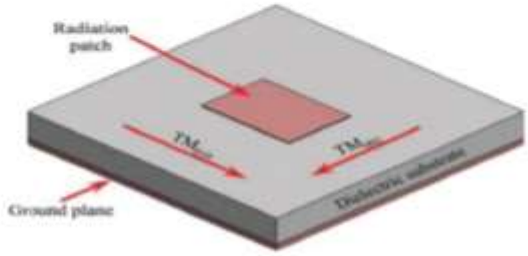

Fig. 6: Microstrip patch antenna temperature sensor, [49]

4.3 Survey of Antennas for Health Care Application

Antennas and their propagation are vital in body-centric communication networks since the antenna serves as a transmitter or receiver. As a result, if the antenna's performance is poor, it will have an impact on the entire system's performance. Integrated health monitoring devices are extremely beneficial in early detection of life-threatening illnesses such as diabetes, and cancer and they considerably minimize the expense and inconvenience of keeping patients in hospitals, [62]. Because of the desire for health monitoring implanted devices, the demand for adjustable portable technology in medical applications is fast increasing. The MPA is the most sophisticated of the several forms of printed antennas for biological applications, [63]. To study practical breast virtual imaging, a metamaterial-based nine-antenna sensing system was used. To obtain the picture of a breast phantom and precisely identify the localized region and existence of many breast tumor sites, a data preparation delay multiplication and sum (DMAS) method was used to analyze the recorded backscattered signal.

This ultra-wideband patch antenna has deep penetration and higher resolution. It gives a stable omnidirectional radiation pattern which is the primary requirement for microwave imaging, [64].

An E-shaped microstrip patch antenna, was built and assessed which was tested on a human phantom model's body and also in a space utilizing various conducting materials. It enhances people's lives by addressing concerns like patients' safety, compactness, and biocompatibility, [65]. A double-patched antenna sensor to investigate the performance and responsiveness of pneumothorax diagnostics was suggested. The sensor is secure, dependable, portable, and simple to operate. A parametric research was carried out utilizing reduced rectangular cell numerical methods. The fluctuation of the S12 parameter about frequency was evaluated to differentiate between healthy and pneumothorax patients. MRI-based anatomical models are often updated to replicate a pneumothorax event in a true clinical case, [66]. CST software was used to simulate an RF microstrip patch sensor for biological purposes. The sensor's response to glucose solution, water, and haemoglobin was then simulated using COMSOL multiple physics.

Partial differential solutions are obtained with this program. When the value of the substance's permittivity changes, the frequency response changes, and the suggested sensor may be utilized to calculate the level of blood glucose by detecting varying plasma permittivity, [67]. For biological applications, a rectangle-shaped insert fed patch antenna using DGS was devised.

By inserting six rectangular-shaped slots upon this ground plane, a large quantity of current density was collected on the patch antenna. Because of its ease of fabrication, minimal cost, and light weight the suggested antenna is ideal for medicinal Broadband applications, [68].

A flexible E-shaped patch antenna was proposed that may be placed in touch with human skin. Microwave scanning of biological components has gained a lot of attention because of its ability to penetrate the images of the breast. The suggested planar flexible antenna has several applications, including the development of wearable medical devices, [69]. Miniaturized metamaterial circular patch antennas for biomedical purposes were developed. Metamaterial reduces the antenna's size and is also a new design approach utilized in medical applications such as cancer therapy, brain signal processing, cancer cell diagnosis, patient monitoring, blood pressure monitoring, and so on, [70]. Using HFSS software, a hexagon patch antenna for biosensing was simulated. Because of the biomaterials used to create the antenna, it may be used on human surface and even within the body. It has low volume, cheap cost, small footprint, is lower in weight, reduced dimensions, and is simple to fabricate, [71]. Using IE3D, a rectangular patch antenna with a microstrip feed was simulated that is useful in communication systems for a variety of applications, including biological applications such as pacemakers, [72]. To maintain the operating frequency of 2.4-2.6 GHz, a U-shaped slot rectangular patch antenna was constructed and simulated and its performance was investigated using several flexible substrate elements such as RT/Duroid, polyethylene, Teflon, polyamide, epoxy, and PDMS. This antenna has various advantages simple, light in weight, small, and cost-effective. It may be suitable for several biological applications, like health care, glucose level, and digestion monitoring, [73]. A T-shaped antenna that can localize and identify brain distortions was demonstrated. The tumor was identified by using six layers humanoid phantom model. It is centered on the fact that the dielectric behavior of normal tissue and cancer is different. The proposed sensor has the advantage that it can detect cancer in various positions, [74]. An open ends slot free miniature microstrip antenna was built and analyzed for body biological applications and to lower microstrip losses. Intrinsic matching and a defective ground configuration are used to reduce mutual coupling impact.

The antenna's entire performance was evaluated using a three-layered human phantom prototype. It has a variety of uses in cancer diagnosis, biological research, and health monitoring, [75]. The analysis and construction of microstrip feed on-body fitted adjustable UWB antenna was presented. A three-layer human spectral model comprising of muscle, fat, and skin is constructed. The antenna is adaptable, unique, and compact in design. It has the potential to make a significant contribution to biological applications, [76]. A coplanar waveguide fed single-layered microstrip antenna array was reported. The suggested concept uses inexpensive adhesive copper sheets instead of traditional silver nanoparticle ink to create four radiating components with a single CPW feeding. The antenna is cost-effective and low profile with wearable applications such as wireless charging of implanted medical devices, [77]. Figure 7 depicts the example of a patch antenna inside the human phantom model, and Table 3 (Appendix) gives the summary of antennas for healthcare applications.

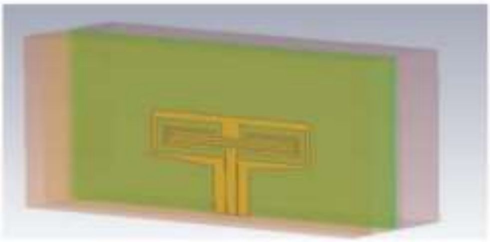

Fig. 7: Patch antenna inside Human Phantom Model, [78]

4.4 Survey of Antennas for IoT Application

Antennas play a vital part in wireless sensing devices, which is going forward into a future well with rapid growth of IoT techniques, with rising applications in industries such as surveillance, agriculture, smart appliances, navigation, and sustainable cities. Concise and readily accessible antenna designs have gained a lot of attention in recent years because of the need for multi-frequency and multi-functional antennas in telecommunications, [79]. The IoT, which links devices to the Internet through wireless technology, has caused profound changes in people's social life in recent years. Wsns devices capture a wide range of data about people and objects. It is feasible to forecast and improve people's behaviour by studying this data, and new economic opportunities emerge, [80]. Microstrip polygon shape patch antenna for the Internet of Things was proposed. To achieve the necessary resonant frequency, the antenna is first analyzed using a basic circular-shaped patch antenna, and then using the equal area idea, a hexagonal-shaped microstrip antenna is created. The polygonal antenna is now described as a mix of six rectangles and a single hexagon. It works with Bluetooth, Wi-Fi, radio location, and RF gadgets, [81]. For microwave sensor applications, a unique octahedral multiband frequency reconfigurable antenna was designed. The reconfigurability was done by employing PIN diodes changing operation since the diodes have a quicker switchable speed and are less expensive. Radio sensing applications and Wireless communications use it, [82]. A multiband circular polarization microstrip antenna was devised for IoT applications through satellite navigation. The suggested antenna is well suited to oil and gas, marine commerce, aerospace, and defense applications, [83]. A circularly polarized right-handed microstrip antenna was depicted with a cross slot in the ground plane in between the patch and feeding line which is fed via aperture coupling. Because of its small size, it can be easily incorporated into so many IoT sensors. It is extremely beneficial in terms of security, and efficiency, as well as in the home automation concept, [84]. A small rectangular patch antenna was proposed with many slots to extend the frequency spectrum for IoT applications in the ISM band. This reconfigurable antenna has a narrow and small construction and a lower dielectric substrate, making it suited towards IoT applications, [85]. A microstrip feed fish-like three-star antenna configuration was given. DGS is also used in the model to improve gain, multiband responsiveness, and bandwidth. The suggested antenna is distinguished by its ease of feeding, small weight, polarization variety, low cost of manufacture, and ease of construction. It works in the Wi-Fi, Bluetooth, and Wi-Max frequency bands and is ideal for the Internet of Things. For telecom applications, it could also function in the GSM 900 band, [86].

To improve the gain of a rectangular patch antenna, two T-shaped gaps cut in the ground plane was studied. Climate observation, geo-location, equipment condition, and moisture for smart farming, among other IoT applications, are all included in the suggested design, [87].A circular pattern patch antenna was demonstrated that can operate in two bands. It features two semi-circular patches and two stub-filled ring resonators. The antenna is appropriate for transmission across short distances. It may be applied to space communication and the Internet of Things, [88]. A small plane UWB antenna with double band-notched characteristics for Internet of Things applications was constructed. Semi-circular holes, Microstrip line feeding-based circular ring emitter, and annular circle slots are all part of the antenna construction. This antenna was chosen because of its small size, ease of use, and consistent radiation, which is ideal for IoT application, [89].

A CPW feed antenna comprising overlapping circular holes and rounded corners in a rectangular form was designed. It is ideal for a variety of portable hand-held IoT systems because of its tiny size. Its resonating bands may be individually modified by varying the size of the top and bottom panels. It has a directed radiation characteristic and a higher gain while maintaining a reasonable radiated efficiency, [90]. A MPA was built for spacecraft IoT-based systems that operates at 7 GHz. In this paper, a four-layered IoT architectural system is given, and the electric and magnetic frequency domains were utilized to create the model, which was implemented to the lumped port at a frequency of 7 GHz. The antenna is a viable option for interplanetary communications, [91]. Substrate embedded waveguide small antenna sensors working in the IEEE C band were presented. Because of metal bias along the border, the antenna operates as an electrical conductor, while the lack of bias upon the opposite side allows it a perfectly magnetically conductive block. Due to their minimal weight, these antenna designs are particularly beneficial in the field of the Internet of Things and may be simply merged with any form of system, [92]. A multiple band plane circular patch antenna with a stub and ring resonator that is small in size was suggested. The antenna operates on various bands, with a bandwidth optimized for short-range communications.

The proposed design may be used in space exploration, Satellite services communication, fixed wireless transmission, broadcasting location, and IoT applications, [93]. Based on hexagonal construction, a spider-shaped patch antenna was created. A defective ground construction is used to increase the antenna's bandwidth. Wi-Fi, GPS, IoT, and Bluetooth are a few of the applications for the suggested architecture. It operates with several wireless communication devices' frequency ranges, [94]. Figure 8 demonstrates an IoT-based microstrip square patch antenna, and Table 4 (Appendix) represents a survey of antennas based on IoT applications.

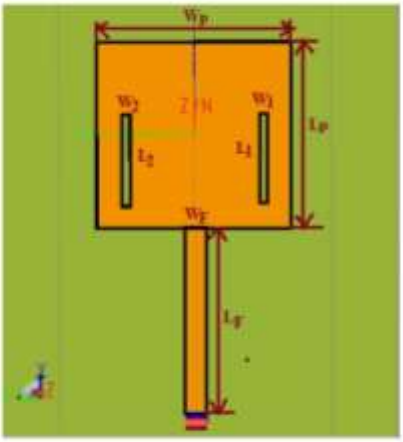

Fig. 8: Microstrip patch antenna based on IoT, [95]

5 Conclusion

In today's smart society, Sensors have decreased in size due to technological advancements, allowing them to be used in a wide range of human activities. Various microwave sensors, such as moisture sensors, temperature sensors, pH sensors, glucose sensors, and wireless sensors based on IoT, have been explored in this review paper. The simulation software and materials required to fabricate microstrip patch antenna sensors, as well as their sensing applications in domains such as agriculture, environmental, health care, and IoT, have been described. This study also contained a survey of antennas based on various uses, as well as a table for comparison. All of the above-mentioned microstrip patch antenna sensor applications are extremely advantageous to human daily life. These antenna sensors may be used in agriculture to detect moisture levels, grain size and porosity, the humidity of rice and grains, and other factors that aid farmers in selecting suitable crops and offer us food quality monitoring. Temperature sensing allows us to monitor the environment in real-time, which is very valuable in hostile environments.

Biomedical sensing helps to evaluate people's health by detecting disorders such as brain tumors, body temperature, cancer, diabetes, and excessive blood pressure. Wireless communication devices based on the Internet of Things are used to send and receive data via Bluetooth, Wi-Fi, Wi Max, and among other technologies. The results of simulations and experiments with various parameters such as gain, return loss, directivity, efficiency, and sensitivity have been reported.

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Conflict of Interest

The authors have no conflicts of interest to declare.

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APPENDIX

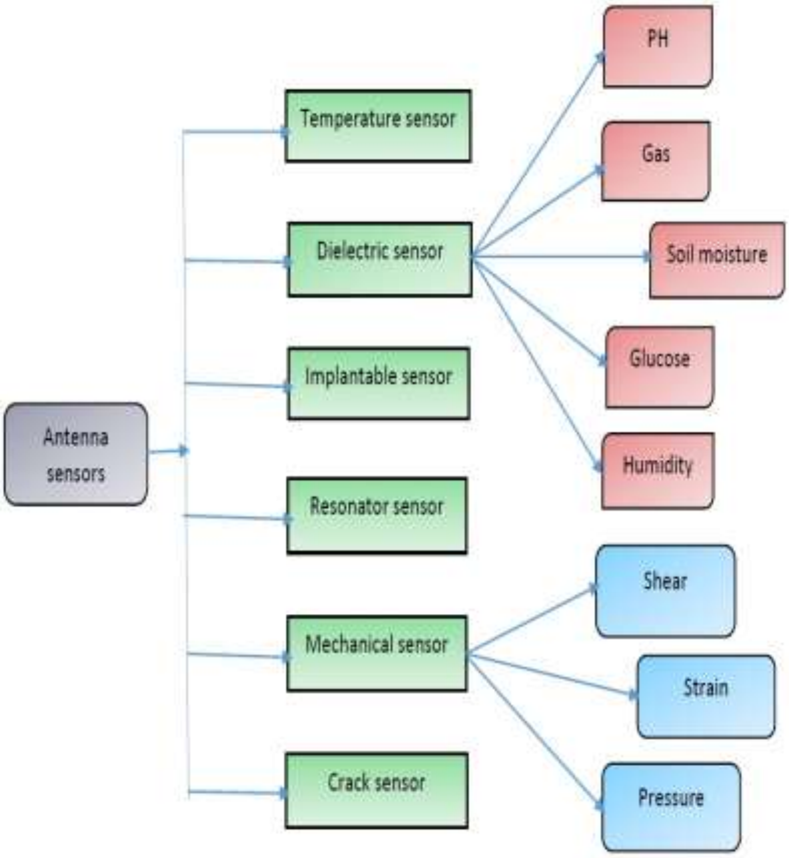

Fig. 4: Different types of Antenna sensors

Table 1. Sensors Based on Agriculture Application

Ref	**Type of Antenna Sensor**	**Dimension**	**Frequency**	**Type of Material**	**Return Loss**
[27]	Circular ring microstrip moisture sensor	12mm*12mm	7.5 GHz	FR-4	-30.99dB
[28]	Circular microstrip resonator sensor	13mm*13mm	11.5 GHz	FR-4	-27.59dB
[29]	Single-band and Dual-band resonant frequency antennas	NA	2.39 GHz	NA	-22.27dB
[30]	Microstrip patch sensor	20mm*20mm	8.1 GHz	FR-4	-28dB
[31]	U-Shape microstrip patch antenna	15mm*15mm	5.2, 6.8 GHz	FR-4	NA
[32]	Microstrip patch antenna with DGS	40mm*40mm	1.7 GHz	FR-4	-15dB
[33]	H-Shape patch sensor	25mm*25mm	5.3, 7.7 GHz	FR-4	-15, -14dB
[34]	Rectangular microstrip moisture sensor	NA	2.68 GHz	FR-4	-35dB
[35]	Microwave moisture sensor	NA	2.45 GHz	NA	-20.28dB
[36]	Circular microstrip patch sensor	NA	6 GHz	FR-4	-28dB
[37]	Microstrip rectangular patch antenna	NA	2.45 GHz	Rogers RT/duroid 5880	-20.28dB
[38]	Microstrip patch antenna	10mm*10mm	5.2 GHz	NA	NA
[39]	Frequency reconfigurable microstrip moisture sensor	30mm*25mm	2-5 GHz	FR-4	-25dB
[40]	Pair of identical microstrip patch antennas	NA	1.85, 2.45, 5.35 GHz	FR-4	NA
[41]	Single and dual resonant rectangular patch antenna sensors	NA	1.5-3 GHz	FR-4	NA
[42]	Single-layer and stacked microstrip antennas	49mm*29mm	NA	GML2032	NA

Table 2. Sensors based on Environment Application

Ref	**Type of Antenna Sensor**	**Dimension**	**Frequency**	**Material used**	**Result**
[45]	Dual frequency microstrip patch antenna sensor	11.8 mm * 9.8 mm	5 GHz and 6 GHz	Rogers RO3006	With the increase in temperature resonant frequency also increases.
[46]	UWB microstrip patch antenna	NA	2.45 GHz	Rogers RO3210	Between the experimental and simulated KT, the normalized variance is 1.39 percent.
[47]	Microstrip patch antenna sensor	39.08 mm * 28.1 mm	5.8 GHz	FR4	It has a return loss range of -21.91 dB to -16.9dB.
[48]	Wireless passive temperature sensor	56.2 mm *70 mm	2.434 to 2.379 GHz	FR4	The sensor's average sensitivity is 347.45 KHz/degree C.
[49]	Dual frequency patch antenna sensor	11.8 mm * 9.8 mm	4.85 GHz and 5.85 GHz	RO3006	As the temperature increases resonant frequency increases
[50]	Reconfigurable sensing antenna	38mm * 38 mm	NA	For supporting the patch and metallic ground it consists of two Fr-4 substrate layers and a middle Duroid/5880 layer with a central square hollow to keep the water inside.	The temperature sensing range is 17 to 70 degrees Celsius.
[51]	Rectangular microstrip patch antenna	110μm * 152μm	264 to 502.2 GHz	PTFE substrate.	The peak gain is 6.54dBi. The sensitivity is 1.588 GHz/K
[52]	Passively wireless sensor with ceramic radiating patch antenna	44.8 mm *68 mm	2.2 GHz	Silver-palladium metallic paste with AlN ceramic material.	104.77 KHZ/degree Celsius is the sensitivity.
[53]	Microstrip patch antenna	13.6mm * 10.9 mm	2.7 GHz and 3.4 GHz	The substrate was Rogers RO3210, and the superstrate was ashes from a charcoal briquette.	The temperature measurement error is ±0.58ºC and ±58.05μm uncertainty is for the superstrate thickness.
[54]	Microstrip patch antenna using Nanocomposites	NA	5.8 GHz	The glass-reinforced epoxy laminate (FR-4) flexible substrate. Nanocomposite as a patch layer	The sensitivity is 32 times higher than its copper counterparts.
[55]	Planar microstrip antenna sensor	38mm * 29.5 mm	3.6–4.2 GHz	FR4	In between the least acidic solution with a pH of 3 and the most basic solution with a pH of 10, the sensor demonstrated a satisfactory frequency response of 130 MHz.
[56]	Wideband microwave sensor	26 mm * 24 mm	2.90 GHz to 18.0 GHz	FR4	It gives −26.73 dB return loss.
[57]	Microstrip patch antenna sensing system	57.6mm * 47.6mm	2.45GHz	Taconic TLY-5 substrate	The reflection coefficient decreases as percentage of salt and sugar increase.

Table 3. Sensors based on Health care application

Ref	Type of Antenna Sensor	Dimension	Frequency	Material used	Result
[60]	Metamaterial inspired nine antenna sensor array	27.5 mm *19.4 mm	2.97 GHz	FR4	The reflection coefficient is < -10 dB
[61]	E-shaped microstrip patch antenna	36mm *32mm	405 MHz	FR4	Human tissue has a return loss of -17.96 dB.
[62]	Dual patch antenna sensor	2.9 cm * 2.9 cm	1 – 4 GHz	Rogers RO3210	At 1.87 GHz, the variation of the S12 parameter with frequency is examined to discriminate between healthy and pneumothorax instances, with a variance of 20.1 dB.
[63]	RF patch antenna sensor	35mm * 35 mm	1.958 GHz.	FR4	According to the CST simulated findings, the feed line with a diameter of 11.25 mm has the maximum Q factor.
[64]	Inset feed patch antenna having DGS in a rectangle form.	46mm *38mm	2.45 GHz	Taconic TLX-8	-30dB is the return loss. The antenna's directivity gain is 7.04dBi.
[65]	E-shaped flexible microstrip antenna	40mm * 10mm	2.54 GHz	NA	The simulated |S11| parameter in dB (20 log10 |S11|)
[66]	Metamaterial circular patch antenna	10mm *10mm	2.4GHz	Rogers RT/duroid5880	Circular and rectangular patch antennas have a return loss of -31dB and a simulated gain of 7dBi, respectively. The circular patch antenna with metamaterial has a return loss of -31dB, whereas the Rectangular patch antenna with metamaterial has a simulated gain of 6dBi.
[67]	Hexagonal microstrip patch antenna	21.8mm * 21.8mm	2.47 GHz	The substrate is a silicon wafer and the ground plane is made of tungsten.	The radiation efficiency is 95.37 percent, with a gain of 4.39, and a directivity of 4.99. The antenna resonating frequency is 2.47 GHz having a directivity of 5.909 with a gain of 4.91 when positioned on the body, although the radiation efficiency drops to 82.98 percent.
[68]	Rectangular microstrip patch antenna	200mm * 200mm	403 MHz, and 720 MHz	Roger has dielectric constant of 10.2	The antenna includes a MICS band with a core frequency of 403 MHz and another band with a center frequency of 720 MHz, according to the simulation results.

Ref	**Type of Antenna Sensor**	**Dimension**	**Frequency**	**Material used**	**Result**
[69]	Rectangle microstrip patch antenna with a U-shaped slot	65.6mm *74.1mm	2.4-2.6 GHz	Epoxy, Polyethylene, Teflon, RT Duroid, Polyamide, and PDMS types flexible substrates.	Reflection coefficient (S11< -10dB) The largest value of S11, -34.05dB, was attained by PDMS, while the least value of return loss, -20.04dB, was achieved by polyethylene.
[70]	MPA with a slotted T form	29.99 mm*29.99 mm	910 MHz	FR4	The given antenna has a reflection coefficient of -35.58 dB. At 134 degrees, the highest gain attained at the central frequency is 3.12 dB.
[71]	A tiny microstrip antenna with an open end slot feed.	53.97mm*46.67mm	2.45 GHz	Teflon	-46.64dB is the reflection coefficient and the directivity is found to be 7.12dBi respectively.
[72]	On-body matched UWB antenna	40mm *40mm	5.93GHz	FR4	The return loss is -41.45dB. The directivity value of the antenna is 5.36dBi.
[73]	Coplanar waveguide fed microstrip patch antenna array	280mm * 192 mm	2.68 GHz	Polyethylene Terephthalate (PET)	The simulated gain is 10dBi.

Table 4. Sensors based on IoT application

Ref	Type of Antenna Sensor	Dimension	Frequency	Material used	Result
[77]	Microstrip polygon-shaped patch antenna	45 mm*55 mm	6.56 GHz, 5.8 GHz, 4.39 GHz and 2.39 GHz	FR4	At 2.39 GHz, the antenna's maximum gain is 11.3dBi.
[78]	Octahedron frequency reconfigurable multiband antenna	NA	8.31-8.90 GHz, 6.3-6.78GHz, 4.75-5.72GHz and 1.4-1.73GHz	Rogers RT/Duroid 5880	NA
[79]	Multiband circularly polarized microstrip antenna	37.26mm*28.83mm	8.4 GHz, 6.76 GHz, and 5.8 GHz	FR4	At Frequency, 5.8 GHz Return loss is -36.67 Gain(dB) is 3.947 At frequency 6.76 GHz Return loss is -27.22 Gain is 5.052 At frequency 8.4 GHz Return loss is -40.82 Gain is 11.168
[80]	Microstrip antenna with right-hand circular polarization	4mm*4mm	17 GHz	Rogers RO4725JXR	The gain of the antenna is 5.8dBi
[81]	Reconfigurable microstrip patch antenna	27µm*30µm.	2.4-2.5 GHz	FR4	-5 decibels is the return loss.
[82]	MPA in the shape of a triple starfish	110mm * 90mm	5.83 GHz, 4.83 GHz, 3.22 GHz, 2.41 GHz 0.79 and GHz	FR4	The S11 = -10 dB
[83]	Rectangular microstrip patch antenna	82.295 mm*105.41 mm	433 MHz	FR4	It is discovered that the return loss is -15.186518 dB and the gain is 2.194 dB.
[84]	Dual-band circular patch antenna	30mm*20mm	3.5 GHz and 6.6 GHz	FR4	For central frequency 3.57 GHz Return loss is -17 dB For central frequency 6.6 GHz Return loss is -11.7 dB
[85]	UWB antenna with a small plane design	24mm*26mm	3.5 and 5.5 GHz	FR4	It emits omnidirectional radiation with a 98.585 percent efficiency.
[86]	Dual ultra wideband CPW fed printed antenna	25mm *35mm	2.4GHz and 3.4GHz	FR4	It has a maximum gain of 8.9 dB
[87]	Microstrip patch antenna	5.2cm*5.3cm	7 GHz	NA	The return loss (S11) is −20.5 dB
[88]	Substrate integrated waveguide-based antenna		5.8 GHz	Arlon AD270	Its return loss is -37.0043 dB
[89]	Antenna in the shape of a spider's web	30 mm * 20 mm	8.53 GHz, 7.86 GHz, 7 GHz, 5.2 GHz and 1.8 GHz	Roger Ro4003	For frequency 1-10 GHz Return loss is -20 dB
[90]	Spider-shaped microstrip patch antenna	29 mm*40 mm	3.72 GHz, 2.5 GHz and 1.48 GHz	FR4	At Resonant frequency{ GHz} 1.48, 2.5 and 3.72 Reflection coefficient (dB) is −31.1357, −11.7089 and −16.0631 Gain {dBi} is 2.6342, 6.3373 and 3.8338