# Stretchable Textile Antennas

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Adaptations of smart systems for on-body wearable applications for human well-being, health monitoring, and observing human movements have grabbed attention. More flexible electronic components are becoming a part of wearable systems as they offer greater flexibility, comfort during wearability, and ease of handling. Wearable sensors, energy-harvesting devices, epidermal electronics, and a variety of electronic circuits have been developed and used in health monitoring.

wearable textile antenna multifunctional antenna lattice hinge design e-textile

polydimethylsiloxane stretchable antenna

## 1. Introduction

To convey sensory information and access remote diagnosis through wearable wireless communication, an antenna is required. Real-time measurements related to physiological aspects such as heart rate, human body movements, intrinsic strain measurements, environmental humidity, and body temperature through wireless sensor networks (WSNs) and body sensor networks (BSNs) require more flexible electronic components [1][2][3][4]. Applications such as humanoid robotics, human–machine interactions, and prosthetics also require flexible electronic components. WSNs and BSNs integrated with functional devices for such end-use applications demand flexibility, stretchability, and conformability from embedded devices in these networks. Materials that offer such a variety of properties create the possibility of making flexible electronic components [5]. Additionally, such materials can also be used to produce multifunctional devices with added functions. Many flexible antennas have been fabricated and are effective for wearable applications, but they are limited to a single end-use application, namely the receiving or transmission of electromagnetic (EM) radiations [6][7]. In some other reported research, an antenna and a strain sensor are typically treated as separate devices within a wearable system [8][9]. Applications, such as strain sensing parallel to communication, require antennas to be made of stretchable materials with a high modulus that can attain a high elongation before break. Antenna sensitivity toward stretching can be utilized as a strain-sensing factor [10]. During practical end-use applications, when a stretchable antenna experiences uniaxial strain or deformation, its resonance frequency changes accordingly. This change in antenna resonance frequency can serve as a signature of deformation due to applied strain, indicating the potential use of a stretchable antenna as a strain sensor [10][11][12][13]. Using a multifunctional antenna in a wearable system can be beneficial in reducing the number of devices in the wearable system without compromising its functionality.

The use of multifunctional devices also minimizes the problem of complex wiring, which is prone to damage and is required to acquire sensory data in wearable smart systems. Similarly, a wearable system with multifunctional devices can solve integration challenges with any garment [14][15]. Considering these practical end-use challenges and limitations, a wearable system with multifunctional devices that offers equal functionalities, similar to a wearable system with more nodes and sensors required for separate functions to analyze but with less complexity, would be advantageous [16]. **Figure 1** illustrates an overview of the potential end-use applications of a strain sensor stretchable antenna, including the detection of Edema disease, monitoring the joint angles in robotic hands to control movement, assessing inflated food packages due to spoilage, and various fields such as sports, healthcare, rehabilitation, structural health monitoring, and smart packaging. These are some of the possible applications where the proposed stretchable textile microstrip patch antenna can be used.

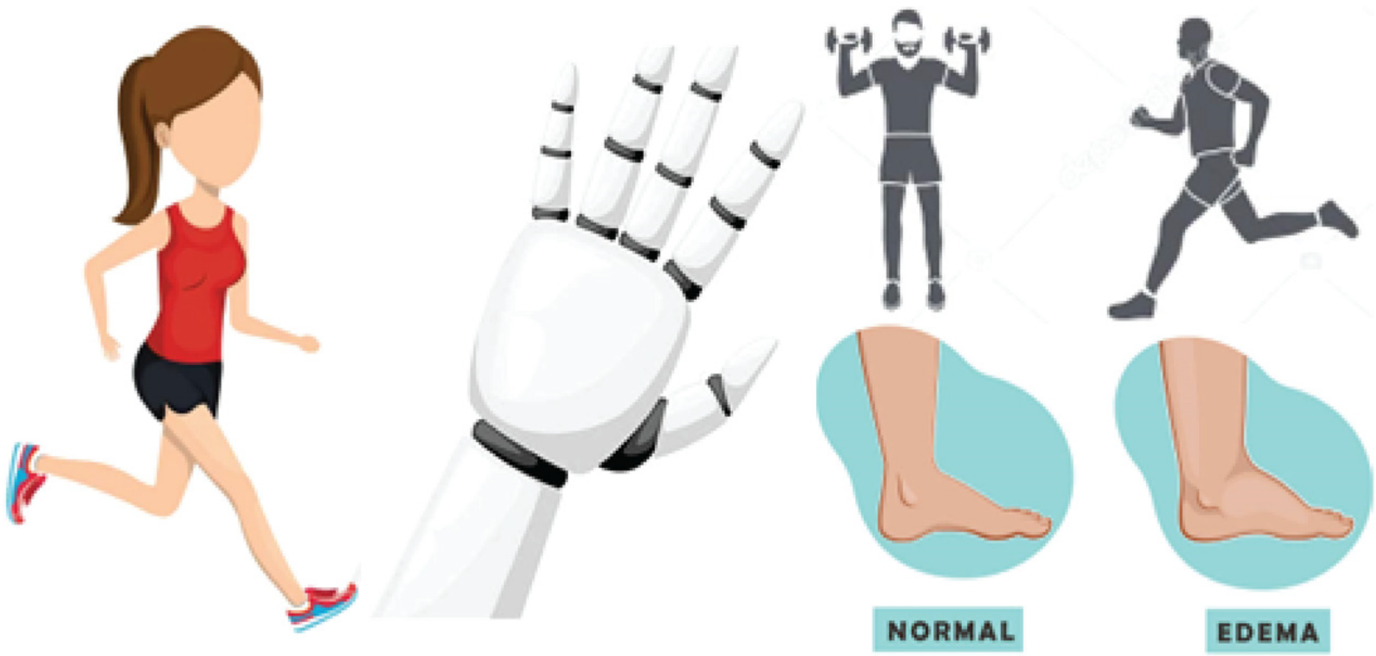


**Figure 1.** Overview of the potential strain-sensing end-use applications for multifunctional stretchable textile antennas.

## 2. State-of-the-Art Stretchable Antennas

In recent years, several stretchable antennas have been developed [6][17][18]. The choice to fabricate a stretchable antenna with the desired EM properties for a wearable system depends on various factors. These include the availability of stretchable materials, both conductive and non-conductive, the space available for antenna integration into the wearable system, and the required operating frequency range [19][20]. More importantly, the incompatibility of the physical parameters among the different materials used in fabricating a patch antenna makes the task of pasting multiple layers, while still leaving their stretchability intact, challenging.

Various conductive materials have been employed to construct stretchable antennas, including Silver-Polydimethylsiloxane (Ag-PDMS) composites, metal nanowires, and liquid metal alloys. However, the poor conductivity of these materials remains a significant concern [17][21][22]. While these materials offer improved stretchability, their EM performance in radio-frequency (RF) wireless technologies still requires enhancement. To address this issue, more recently [10], conductive textile fabrics such as copper and silver-coated polymeric textile fabrics have been utilized and given a serpentine structure. Consequently, using a highly conductive textile fabric with a serpentine structure provides better stretchability and suitable EM performance.

To fabricate a stretchable patch antenna, one option is to use conductive and dielectric materials that have a stretchable character. However, this way of constructing a stretchable patch antenna is difficult, as neither the conductive and dielectric materials will not be compatible in their stretchability. One will offer more stretchability than the other when sandwiched together in a patch antenna shape. Alternatively, the antenna design itself can be modified to allow for an extra amount of stretching, or a combination of both approaches can be employed. Each method of fabricating a stretchable antenna has its advantages and limitations. In recent developments, in an example where an antenna design was modified for a patch antenna to obtain stretchability, optimally patterned 3D structures such as serpentine and helical coils made from conventional non-stretchable materials like copper foil were utilized for fabricating stretchable patch antennas [5][10]. These structures were then deposited onto stretchable dielectric materials such as Ecoflex, Solaris, and PDMS. This approach involved a complex process of designing the antenna with a 3D serpentine pattern, simulating it, using specialized software to design and cut the intricate pattern, and finally, employing a delicate fabrication process to deposit the 3D serpentine patterns onto the stretchable material. Various parameters, including the arc angle, need to be considered while simulating serpentine-structure-based antennas [10][23]. The resulting serpentine patch antennas exhibited an improved stretchability, but they also resulted in a higher Surface Absorption Rate (SAR) due to the serpentine-structured ground plane. The limited surface area of the conductive material in the serpentine ground plane compared to a solid layer in the traditional patch antenna topology contributed to this increase in the SAR [24][25].

Other recent advancements in the field of stretchable antennas include the use of serpentine structures (stretchable three-dimensional structures with repeated unit cells of the same shape), materials such as silver nanowires (AgNWs), and liquid metal alloys [8][20][26][27][28]. In another notable development [10], for fabricating a stretchable antenna, the antenna was based on a serpentine structure. Here, a stretchable, knitted, silver-plated textile fabric (MedTex, Smethwick, UK) was converted into a serpentine structure first and then joined with the stretchable Ecoflex substrate to fabricate a stretchable patch antenna. Though the serpentine structure exhibited a high sensitivity toward stretching due to the use of stretchable conductive fabric over a stretchable dielectric substrate, the fabrication process in shaping the serpentine structure involved a few steps followed by a delicate step of depositing the serpentine conductive layers over the stretchable Ecoflex layer to ensure their integrity and shape remained intact. There is always a trade-off between the mechanical stretchability and EM performance of the meshed/serpentine antenna. Another recently reported approach [29] employed conventional non-stretchable electrodes or sheets (such as stiff metals like copper foil) patterned in a repeated unit cell to make them stretchable. These serpentine layers were combined with a PDMS substrate to fabricate a stretchable antenna. Other research has explored strategies such as Kirigami-like structures and twisted helical spring structures to enable stretchability in materials that were originally non-stretchable [30]. In terms of quantifying stretchability, AgNWs achieve a minimum of 15% stretchability, while serpentine-based antennas can achieve a maximum stretchability of 100% [10][20].

Our research proposes a simpler, easy, and novel method for fabricating stretchable textile-based antennas, based on transforming plain conductive layers of a patch antenna into lattice hinge design (LHD) conductive layers. The structure of an LHD and its design parameters are shown in **Figure 2**a and **Figure 2**b, respectively. The novel LHD approach, also called living-hinge, is an innovative way of transforming non-stretchable materials into stretchable ones by introducing a lattice framework with uniquely shaped hinges and is adapted in the research work. The basic idea behind a lattice-hinge technique is to construct a framework of regularly shaped hinges throughout the surface of the non-stretchable material that helps the material to flex and expand while maintaining its structural integrity. Systematically positioning the lattice-hinge framework over the materials' surface ensures their uniform and controlled stretchability. This design enables the transformation of a non-stretchable sheet (such as a wood sheet) into a stretchable and bendable one by patterning the sheet in a way that allows for deformation when stretched or subjected to uniaxial strain. Unlike serpentine structures, this simple antenna design facilitates the transformation of a non-stretchable conductive electrotextile into a stretchable layer with a minimal impact on its electrical performance. The LHD is formed by creating parallel, overlapping longitudinal slots of a specific length and width, which divide the sheet into repeated linked sections capable of stretching compared to a plain sheet without such longitudinal slots. This way, an array of parallel columns of longitudinal slots is formed; this array helps to sustain deformation in a uniaxial direction, while also enhancing the sheet's flexibility when handled. These design principles are followed in the research to convert a non-stretchable conductive textile fabric into a stretchable structure by incorporating the LHD. This innovative approach opens up possibilities for diverse implementations and a variety of antenna designs to obtain enhanced antenna stretchability. **Figure 3** provides a conceptual overview of the developed conformable, flexible, and stretchable microstrip patch antenna through an LHD.

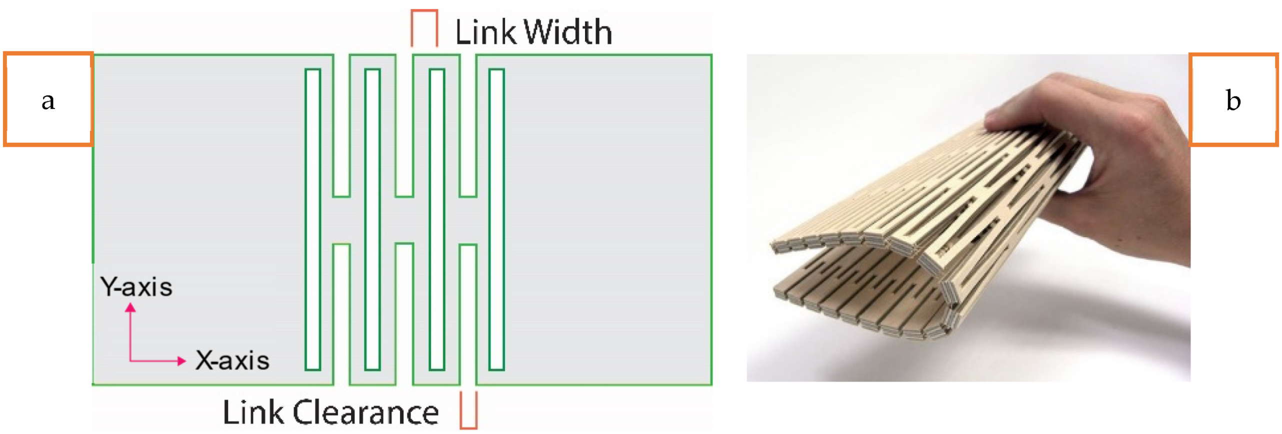


**Figure 2.** (**a**) The lattice hinge with parameters and (**b**) the lattice hinge pattern on a wooden sheet.

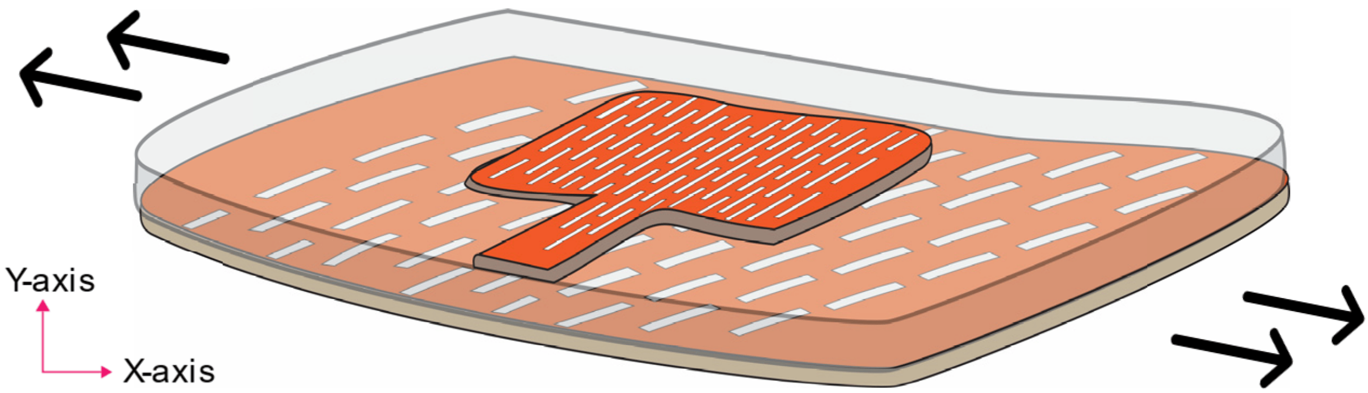


**Figure 3.** A schematic view of the LHD-based stretchable microstrip patch antenna.

One significant advantage of using e-textiles with a lower surface resistivity is the reduced cost of integrating antennas into garments. Additionally, researchers' proposed LHD-based stretchable antenna fabrication method offers minimal change in its electrical performance while providing stretchable characteristics. The distinguishing feature of the research from the existing stretchable antenna literature lies in the simpler and novel technique employed to create a fully textile stretchable antenna. This work can be further extended by exploring different design patterns to convert non-stretchable materials into stretchable ones.

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