International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Evaluation of Antenna Designs for Wearable Technology: A Literature Review

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Doi: https://doi.org/10.55248/gengpi.5.0724.1711

A B S T R A C T

Research into improving the functionality and capacities of wearable technology has surged as a result of its fast progress. The functioning of wearable technology is largely dependent on antenna design, which provides wireless connectivity and communication. This study of the literature searches many online sources for pertinent research on the various antenna designs for wearable technology. The findings verified that the materials vary based on the design being employed. An analysis was conducted on the gain, frequency, materials, and sizes. The review excels at synthesizing research and literature despite its restricted resources.

Keywords: Frequency; Gain; Antenna Design; Wearable Technology; Connectivity

1. Introduction

The majority of electronic systems employ antennas as means of transmitting and receiving electromagnetic signals. It serves as a link between open space and electrical circuits, enabling the transmission of electromagnetic waves into the atmosphere or the receipt of these waves and their conversion into electrical signals [1]. It consists of radio frequency (RF) waves traveling between two places in space via a metal conductor. This gadget has the ability to send and receive signals. A receiving antenna receives radio signals that are created when a voltage is provided to a transmitting antenna. The receiving antenna then converts the radio signals back into electrical energy in the form of information [2]. Antenna technology has improved significantly in the field of advanced wireless communication. Antenna technology has improved significantly in the field of advanced wireless communication. New designs and technological advancements have produced a new generation of antennas that enable complicated applications and offer greater performance [3].

Electronic devices that are worn on the body or embedded in clothing or jewelry, or implanted in the body, are known as wearable technology. The devices are capable of tracking a user's physical activity, monitoring vital signs like heart rate, and providing notifications of incoming calls and messages. Smart clothing, such as shirts and pants embedded with sensors, are another example of wearable technology that can be used to monitor health, such as posture and breathing, and provide haptic feedback to wearers to improve their movements [4]. The research and development of miniature wearable antennas has increased recently with the growth of the Internet of Things (IoT) and wearable technologies. The development of wearable antennas is now underway for a number of wireless applications, including wireless body area networks (WBAN), wireless personal area networks (WPAN), wireless local area networks (WLAN), and cellular communication. The antennas are becoming smaller, flexible, and even integrated with textile materials [5].

Since wearable antennas are the hub for wireless sensors in biomedical applications, they have attracted interest. Being flat, lightweight, flexible, non-toxic, and inexpensive are the difficulties in building antennas for biomedical and health monitoring systems [6]. When these wearable antennas are positioned near to the body, their high back-lobe radiations may result in higher electromagnetic absorptions [7]. Metamaterial surfaces or artificial ground planes can be used as a substitute to get around these restrictions. These surfaces help to further improve the antenna performance of the patch antenna in terms of gain, directivity, efficiency, and bandwidth by suppressing the surface wave and providing in-phase reflections [8].

1.1 Aim of the Review

This paper's goal is to provide a thorough synthesis of the corpus of research on antenna designs intended primarily for incorporation into wearable technology and gadgets. This study aims to present a thorough analysis and synopsis of the current state of knowledge in this quickly developing topic by an extensive assessment of academic works, research articles, and technical publications. This synthesis seeks to provide insightful analysis and new viewpoints for practitioners, engineers, and researchers working on wearable technology development by exploring the wide array of antenna designs, materials, fabrication methods, and performance attributes relevant to wearable applications [9]. Through this, it hopes to further knowledge and develop antenna design techniques that are optimized for wearable device integration. This will enable the development of creative, high-performing wearable technology solutions across a range of applications and domains.

2. Design considerations for wearable antennas

This section shows the considerations upheld such as the key parameters in designing antennas and the trade-offs between different design parameters.

2.1. Design parameters for designing antennas

Modern technologies and various applications, particularly in sensors, biomedicine, displays, solar panels, eyewear, smart cities, integrated circuits, and wireless body area networks (WBAN), have complicated wearable technology and flexible electronics. Their key properties include elastic, flexible, and foldable, and they can withstand harsh weather conditions. They can also withstand mechanical deformation [10]. The functionality of a wearable antenna, an essential component of the radio frequency front-end of wearable devices, directly influences the ability of the human body's wireless communication system to function correctly. It typically serves as an energy converter to receive and radiate radio waves. As a result, the easiest way to gauge an antenna's performance is to look at its characteristics, which are often assessed in terms of gain, impedance matching, and antenna layout [11]. The right amount of matching between the antenna and feeder is referred to as impedance matching, and it directly affects whether the feeder signal can be delivered to the antenna through the feeder. The link between the properties of the radiation field and the spatial angle is characterized by the antenna pattern, which also represents the radiation characteristics in free space and at various azimuths. Although the gain, which often refers to the direction of the highest radiation intensity in space, defines the power of the antenna's radiating capabilities in a certain direction [12].

2.2. Trade-off between different design parameters

The complex trade-offs involved in maximizing performance for these devices are highlighted by recent studies in wearable antenna design. Remarkable studies published in prestigious publications emphasize how crucial it is to strike a balance between performance and size measurements. A review of the literature by [13] addresses the requirement for small antennas with sufficient gain and radiation efficiency. They highlight the use of cutting-edge downsizing methods and cutting-edge geometries to accomplish this delicate balance.

Furthermore, research on the relationship between durability and flexibility, as demonstrated in the study of [14], illuminates the difficulties engineers encounter. The flexibility needed by wearable antennas to fit the curves of the body and provide comfort and freedom of movement must be weighed against the possibility of deterioration over time. It is critical to use appropriate materials and design techniques in order to balance these competing objectives.

Recent research by [15] addresses the trade-off between biocompatibility and performance and highlights the vital need for materials that have acceptable electrical characteristics in addition to being biocompatible. This is a serious problem since biocompatible materials might not naturally have the qualities needed for the best antenna performance. In order to successfully overcome this obstacle, researchers investigate novel material compositions and production methodologies.

Furthermore, discussions on bandwidth and size trade-offs, as highlighted by [16] underscores the complexity of supporting multiple communication standards within limited device dimensions. Wide bandwidth requirements conflict with the constraints of size, necessitating sophisticated design methodologies such as frequency tuning and multi-band antennas to strike an appropriate balance. According to the journal article, Frequency tuning emerges as a crucial technique, enabling the adaptation of antenna characteristics to specific frequency bands, thus maximizing efficiency within the given size constraints. Additionally, the integration of multi-band antennas further enhances versatility, allowing devices to operate across multiple frequency ranges without compromising on performance.

2.3. Significance of the review and design considerations

Antenna design stands as a crucial element in the evolution and functionality of wearable technology, offering far-reaching implications that shape its usability and effectiveness. At the heart of this significance lies the imperative for miniaturization and efficiency [17]. Wearable devices are inherently limited in size, demanding antennas that can seamlessly integrate into their compact forms while maintaining optimal performance. Efficient antenna designs are essential, ensuring reliable wireless connectivity without sacrificing signal quality or range [18].

Wireless connectivity forms the backbone of wearable technology, enabling seamless data exchange and interaction with other devices. Antennas serve as the conduit for this communication, facilitating the transmission and reception of signals across various networks [19]. The design of these antennas directly impacts the performance and reliability of wearable devices, dictating their ability to maintain robust connections in diverse environments, from bustling urban settings to confined indoor spaces [20].

Beyond technical specifications, antenna design profoundly influences the user experience of wearable technology. Well-designed antennas translate into uninterrupted connectivity and enhanced usability, fostering satisfaction among users. Conversely, subpar antenna performance can result in dropped connections, weak signals, or interference, undermining the utility and appeal of wearable devices [21].

3. Methodology

This section covers the overall execution of this literature review such as the identification of studies via databases, data collection, and statement of the limitation.

3.1 PRISMA flow diagram

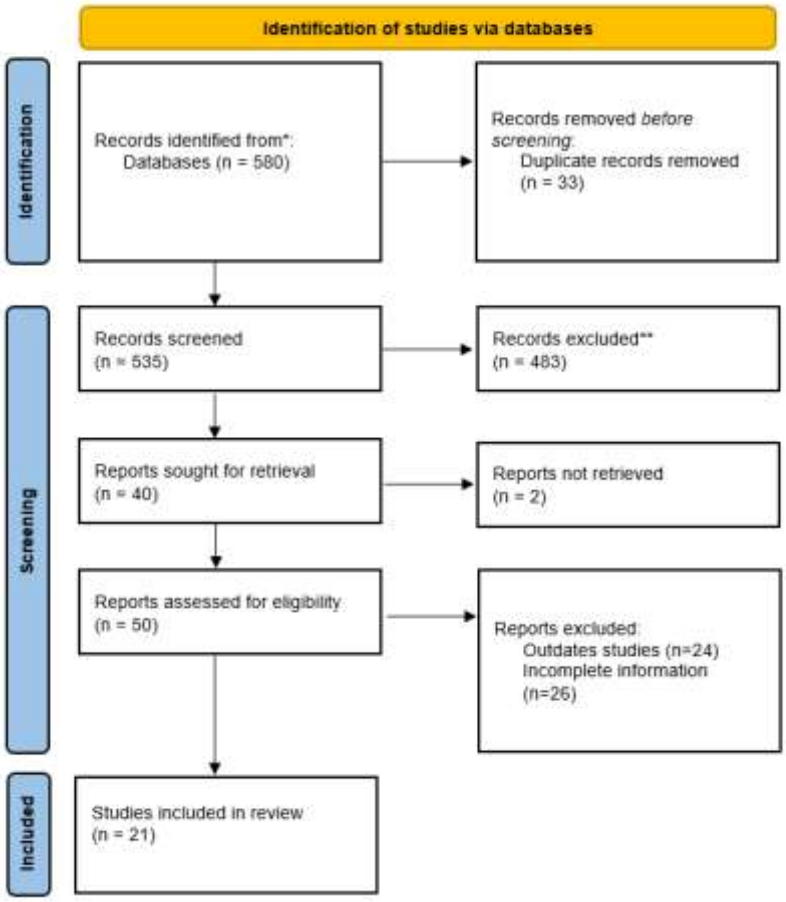

Figure 1. PRISMA flow diagram

Figure 1 shows the technique of leveraging electronic databases to locate pertinent studies for a systematic review is described in the flowchart. It begins with a search of pertinent databases, producing a collection of studies (580 studies were discovered). Then, in order to prevent double counting, duplicates are eliminated (for example, 33 deleted). The screening phase follows, during which research are evaluated in accordance with preset standards in order to be included in the review. Here, many studies (483 out of 535 examined) may be eliminated. The remaining studies are obtained for additional analysis. It's possible that some studies cannot be retrieved (2 not recovered). Lastly, eligibility for the retrieved studies is evaluated using additional criteria. Certain studies may be removed because they are out of date (24 eliminated) or don't have all the information needed (26 excluded). Finally, the articles that only passed the evaluation resulted to 21 articles (see table 1).

3.2. Data collection

A variety of publications, including IEEE Xplore, Scopus, Taylor & Francis Online, Science Direct, ResearchGate, MDPI, IOPScience, and Frontiers, were searched in order to conduct the literature review. A systematic examination of the titles and abstracts of published research publications was conducted using the following keywords: "Antenna Design," "Wearable Technology," "Application to Wearable Devices," and "Antenna." This methodological approach made sure that the body of existing literature was thoroughly examined, which made it easier to comprehend the subject matter and opened the door to perceptive analysis and synthesis.

3.2. Limitation of the review

As part of the screening review, each article was given a rating based on its title and abstract. Each discovered record was thoroughly investigated to see whether it could be included in the systematic review. Certain records must be eliminated in order to narrow the selection down to a more focused list using pre-established standards. While not all of the reports were successfully collected, attempts were made to get reports relevant to these records at the same time. Following the retrieval of the reports, a thorough eligibility evaluation was conducted, leading to the removal of certain reports for the purposes outlined in the study protocol. An extensive range of relevant research is ensured for the comprehensive analysis of antenna design for wearable technology by the systematic screening method.

4. Results and discussion

The results were shown in tabular form for an easier way of understanding the literature review about the different designs for wearable antennas.

4.1. Results

Table 1. Screened Articles

Lead Author	Date	Antenna Design	Size	Main Material Used	Frequency band (GHz)	Gain (dB)	Ref No.
C. Wang	2024	Nanoantenna	20*10 mm^2	PET Materials Substrates	2.02 GHz and 2.3 GHz	−16.02 dB and −19.33 dB	[13]
S. Bhardwa	2023	Planar Antennas	5.5 m* 5.5 m*0.16 mm^2	LoRa Module	0.868 GHz	>0.5 dB	[14]
S. Chrystidass	2023	Microstrip Antennas	1.6*1.5 mm^2	Split-ring Resonator and substrates	5.8 GHz	1.34 dB	[15]
U. Ali	2023	Metamaterial-based Antenna	100*100 mm^2	Conductive and Non-conductive	5.8 GHz	-40 to -34 dB	[16]
Md. Shawan	2023	Metasurface Antennas	25*15 mm^2	Conductive and Non-conductive	2.45 to 3.65 GHz	<1 dB	[17]
G. Phaneesh	2023	Textile Antenna	0.2*0.3*0.08 mm^2	SheildIT and Denim Substrate	2.4GHz	2.086dB	[18]
O. Fiser	2022	Bowtie Antenna	60*60*50 mm^2	UWB Balun	1 to 6 GHz	<-10 dB	[19]
T. Kousalya	2021	Textile Antenna	10 x 9 x 0.05 mm^2	Natural Rubber, Denim And Cotton and Carbon Filter Substance	2.45GHz	7.81	[20]
A. Arayeshnia	2020	Bowtie Antenna	18*18*0.5 mm^2	FR-4 sub-strate	0.75 to 4 GHz	≤- 10 dB	[21]
A. Malempati	2020	Planar Antenna	40*34*1.26 mm	Polymer Composition	2.45 GHz	1 dB	[22]
S. Deepika	2020	Microstrip Antenna	2.5 x 3.5 x 0.07 mm^2	ShieldIt and Denim Cloth	2.4 GHz	-27.01 dB	[23]
B. Fady	2020	Planar Antenna	3.0 × 3.0 × 0.16 mm^2	FR4 material	1.9 GHz, 2.3 GHz, 2.4 GHz,	6.6 dB	[24]

					2.6 GHz, 5.2 GHz. 5.8 GHz		
S. Karthikeyan	2019	Planar Antennas	40*34*1.26 mm^2	Bed Sheet Cotton	2.1 GHz to 4.3 GHz	<-10 dB	[25]
A. Salleh	2019	Antipodal Vivaldi Antenna	500*600*15.20 mm^2	Rogers RO4350B substrate	2.06 GHz to 2.61 GHz	2.45 dB	[26]
R. Abdulhasan	2019	Monopole Antenna	30*31.9*21.6 mm^2	FR4 substrate	3.8 to 10.6 GHz	3.5 dB	[27]
E. Cil	2019	Cavity Backed Slot Antenna	64*60*15 mm^2	Rogers RO3210 laminate	2.4 GHz	1.3 dB	[28]
M. Abbak	2018	Corrugated Vivaldi antenna (CVA)	500*600*15.20 mm^2	FR-4 or Rogers and dielectric materials	3 GHz	5.6 to 10.4 dB	[29]
Md. Mahmud	2018	Microstrip Antennas	76*44 mm^2	Metamaterial-Based Artificial Magnetic Conductor	3.1 GHz, 4.05 GHz, 6.1 GHz	20 dB, 25 dB, 32 dB	[30]
Y. Fan	2018	MIMO antenna with EBG	18.5*18.5*1.27 mm^2	Radiators	2.14 to 2.58 GHz	-15.18 dB	[31]
Suresh Subramanian	2018	Microstrip antenna	27*29*1.6 mm^2	FR-4 or Rogers Material	3 to 15 GHz	<-10 dB	[32]
S. Krishnakumar	2018	Microstrip Antenna	1.93*1.12*0.12 mm^2	Jeans Denim Substrate	2.396 GHz	7.8dB	[33]

Table 1 displays antennas in a range of sizes and forms, from tiny ones measuring little more than a centimeter to considerably bigger ones measuring half a meter. The choice of materials appears to be versatile as well; laminates, conventional circuit board materials (FR4), and even fabrics have been used by researchers. It's interesting to note that the antennas cover a wide range of frequencies, from those needed for radar systems to those for mobile communication, which requires considerably higher frequencies. Gain, which ranges from extremely low to relatively high and indicates how well an antenna concentrates a signal, also appears to be a subject of concentration. This implies that scientists may be developing antennas for uses that call for both stronger, omnidirectional transmissions and weaker, directional ones.

4.2. Discussion

Microstrip patch antennas are one of the popular designs. These low-profile, level patterns are frequently created on circuit boards using conductive patches. They are perfect for mobile phones and other similar devices because of their price, simplicity of production, and interoperability with other electronics. The monopole antenna, a straightforward vertical metal rod frequently seen in vehicle radios or RFID tags, is another popular kind. While materials can vary, brass and copper are frequently used. Dipole antennas are commonly used as reference antennas because of its good directionality and two straight metal rods arranged in a V configuration. These are made of materials comparable to monopoles. These trends—miniaturization for ever-smaller devices—are anticipated to continue in antenna design in the future. This may be accomplished with the use of metamaterials and sophisticated materials. Devices with several uses and little space might be created by integration with other components. Reconfigurable antennas, which may change their characteristics at will, may make it possible for devices to connect to multiple networks or operate in a variety of situations. Lastly, wearable electronics may be comfortably integrated with flexible antennas created using novel materials and geometries.

One of the most crucial components of the ideal wearable gadget is its antenna design, which should allow it to function dependably for an extended amount of time without limiting user activities or altering habit. The device's energy efficiency has to be raised in order to extend the battery's life [43]. Longer battery lifetime can be directly translated into fewer retransmissions and improved link budget through higher antenna gain or pattern diversity, given that RF transmission consumes a significant portion of total energy consumption [44]. Since the antenna, along with the battery, is one of the larger components of the device, convenient form factor is also connected to it. For the sensor to be smoothly integrated into clothes, tiny or flexible stiff antennas are needed [45]. An antenna's frequency response and radiation efficiency alter when it is placed close to lossy human tissue, such as when a person wears it. A body phantom should be used in the design phase to help prevent this, and a ground plane should be used to isolate the antenna from the human body as much as feasible electromagnetically. The overall system efficiency will be preserved if the antenna is made to be resistant to these near-field impacts of the body [46].

4.3. Strengths and weaknesses

It is clear from the data that it is strong point is that it covers a wide range of designs, materials, and frequencies that are employed in current research. This gives an overview of the main areas of interest for researchers in the discipline. The table also includes a summary of each antenna's important dimensions, material, gain, and frequency. This makes it possible to compare several designs quickly. There are restrictions to take into account, though. There may be information insufficient in the table regarding each antenna. It probably leaves out important details like efficiency or radiation patterns, which makes it difficult to assess if a given design is appropriate for a certain use. Furthermore, it appears that fundamental factors like size and frequency are the main emphasis. It's possible that details about cost, complexity, and ease of fabrication of these antennas are lacking. It is hard to judge how feasible these ideas might be in practice due to the absence of useful details.

This thorough literature review is notable for a number of reasons, chief among them being its ability to synthesize a substantial amount of research on wearable technology antenna design under resource constraints. Despite the limited availability of research resources, the researcher used talent to pick and assess publications, indicating their dedication to delving into the details. One commendable aspect of this evaluation is the meticulous consideration given to the vast range of methodologies applied to the dataset. This method not only shows how dedicated the researcher was to learning everything there was to know about the issue, but it also helped them come to significant conclusions. Concerns should also be raised regarding the potential underutilization of antenna designs. The limited number of sources that were available may have caused the focus to be reduced, maybe neglecting certain designs that could have offered useful information on wearable technology. This recognized limitation emphasizes the need for more study to examine a larger variety of antenna designs in order to fully understand their potential for usage in wearable devices. Although this review of the literature does an excellent job of synthesizing data in the context of resource constraints, it is crucial to recognize the inherent limits brought about by the scarcity of alternative sources.

5. Conclusion

The review of the literature looked at the wide range of antenna designs for wearable technology. The researcher looked into a range of design possibilities, including cutting-edge metamaterial structures and well-known microstrip patches. The selection of the material is very important, taking biocompatibility, conformability, and flexibility into account. The frequency band that is being targeted determines the size of the antenna and affects variables like power consumption and data transfer rate. Analysis of gain characteristics was also conducted, emphasizing the trade-off between directionality and efficiency. Antenna design will advance in tandem with wearable technologies. Miniaturization, multi-band functioning, and textile integration.

Acknowledgment

We thank everyone who supported us all the way through, to our adviser, Dr. Edwin R. Arboleda, and to the Department of Computer, Electronics, and Electrical Engineering.

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