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REVIEW ARTICLE

Contactless Human Sensing for Personalized Healthcare: A Review of Wireless Signal Applications in Biomedical Science

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ABSTRACT

Wireless signal applications in biomedical science have tremendously developed to improve people's health care systems and contactless human sensing technologies. This review aims to focus on the current development of wireless microsystems, stressing the application of the wireless microsystem for precise physiological measurement without physical contact. Bio-signals transmitted through wireless telemetry systems help healthcare practitioners cover large numbers of patients continuously without repeated invasive interventions, improving the quality of care. RF systems and data acquisition techniques are critical for constructing wireless biomedical devices with low power consumption, especially in implantable applications. Moreover, depending on the advancements in microtechnology, sensors and actuators are compact and can be combined with communication electronics to produce complex health-checking systems. The review also presents issues like signal distortion and data processing procedure requirements to obtain correct measurements in complicated surroundings. As technology advances in wireless communication systems, their usage in the health sectors advances, and the upcoming innovations should make healthcare better for the patients and efficient for the clinicians. In this vein, this paper posits wireless technologies as crucial to the advancement and contours of the future of personalized healthcare through monitoring and engagement.

Keywords: Wireless sensing ▪ Contactless monitoring ▪ Personalized healthcare ▪ IoT ▪ AI integration

1. INTRODUCTION

The advances in wireless technologies have affected the approaches to patient management, moving from the idea of overall healthcare paradigms. These systems threaten to disestablish conventional physical healthcare systems due to the capacities of remote sensing through contactless methods. Implementing wireless solutions into biomedical systems is highly effective in expanding the range of care and significantly improving the productivity of healthcare institutions [1].

Our research underscores the invaluable role of contactless sensing technologies in personalized care. These technologies enable the collection of physiological and biomedical data from patients without physical contact, thereby reducing patient discomfort and eliminating the risks associated with invasive procedures. This evolution aligns with the growing need for patient-centric healthcare solutions [2].

The elaboration of wireless microsystems creates new prospects for accurate physiological monitoring. These systems use miniaturized sensors and actuators interconnected with sophisticated wireless communication modules; the captured health metrics are accurate and real-time. Of all these, they are most effective in situations where the condition needs to be monitored regularly, for instance, long-term conditions [3].

It is crucial to recognize the pivotal role of wireless telemetry systems in modern healthcare. These systems, which facilitate bio-signal transmission, enable clinicians to screen large patient populations simultaneously, reducing the need for invasive tests and ensuring continuous service. This capability is particularly vital in remote or resource-constrained environments.

Tangible progress in microtechnology and other electronic devices has dramatically improved the capabilities and effectiveness of wireless healthcare technology. From implantable devices that can fit in the human body to portable monitors, these devices must be power efficient and provide reliable signals for consumption in contactless smart biomedical healthcare systems [4].

However, there are hindering factors, which include distorted and noisy signals in the intricate and competitive medical setup. Solving these issues requires highly efficient data processing procedures and adapting to the circumstances to guarantee the validity of physiological recordings in environmental conditions.

Serious advantages that are reachable only with continuous, real-time monitoring are possible with wireless systems. They provide clinicians with early, accurate information to aid in diagnosis, treatment, and patient management. These benefit patients by improving their safety and comfort and reducing their need to visit hospitals.

Wireless technologies in healthcare are not a solitary endeavor. They thrive on the contributions of multiple disciplines, including biomechanical and biomedical engineering, communications technology, and numerical and computational sciences. This collaborative effort is crucial in creating functional systems that can be effectively deployed in diverse clinical environments, underscoring the significance of each field in shaping the future of healthcare.

The future of healthcare is set to be revolutionized by the further development of wireless technologies. As new waves of artificial intelligence and machine learning are projected to integrate with wireless systems, we can anticipate a healthcare landscape that is more intelligent and less dependent on human input. This exciting prospect underscores the potential of artificial intelligence to deliver innovative healthcare solutions.

Recent global health statistics further demonstrate the urgent need for wireless and contactless sensing technologies in modern healthcare systems. Noncommunicable diseases remain one of the leading causes of mortality worldwide, accounting for at least 43 million deaths in 2021, which represents approximately 75% of all non-pandemic-related deaths globally. Moreover, 18 million people died from noncommunicable diseases before the age of 70, with 82% of these premature deaths occurring in low- and middle-income countries. These figures indicate that continuous physiological monitoring is no longer a supplementary healthcare service, but rather a critical requirement for early diagnosis, risk prediction, and long-term disease management. Therefore, wireless and contactless monitoring systems can provide an effective technological pathway for reducing delays in clinical intervention, especially among patients with chronic cardiovascular, respiratory, metabolic, and neurological conditions.

In addition, the global shortage of healthcare workers highlights the importance of scalable and automated digital-health solutions. The World Health Organization estimates a projected shortfall of 11 million health workers by 2030, mainly in low- and lower-middle-income countries. This shortage places substantial pressure on hospitals, clinics, and remote-care services, particularly in regions where access to specialized medical staff is limited. In this context, contactless sensing systems, Internet of Things platforms, and artificial-intelligence-supported monitoring tools can help clinicians observe large patient populations more efficiently while reducing the need for repeated physical visits. Such technologies are especially valuable for remote areas, elderly patients, post-operative follow-up, epidemic control, and home-based healthcare, where continuous and reliable monitoring can improve patient safety, reduce healthcare costs, and support more equitable access to medical services. Figure 1 illustrates the global statistical burden of noncommunicable diseases and explains why wireless and contactless sensing technologies are increasingly important in modern healthcare. The infographic highlights that noncommunicable diseases caused approximately 43 million deaths in 2021, representing about 75% of all non-pandemic-related deaths worldwide. It also shows that 18 million of these deaths occurred prematurely before the age of 70, with 82% of premature deaths concentrated in low- and middle-income countries. These statistics emphasize that continuous physiological monitoring is not merely an optional digital-health service, but a necessary component of early diagnosis, risk prediction, and chronic disease management. Accordingly, contactless and wireless monitoring systems can help reduce delays in clinical intervention by enabling real-time observation of patients with cardiovascular, respiratory, metabolic, and neurological conditions.

Figure 2 presents the projected global shortage of healthcare workers and shows how digital-health technologies can support overstretched healthcare systems. The infographic emphasizes the World Health Organization's estimate of an expected shortage of 11 million health workers by 2030, with the greatest burden affecting low-income countries and the lower-middle-income group. This shortage increases pressure on hospitals, clinics, remote-care services, and post-operative follow-up systems, particularly in underserved regions. In this context, contactless sensing, Internet of Things platforms, and artificial-intelligence-supported monitoring tools can assist clinicians in observing larger patient populations more efficiently. These systems can reduce unnecessary repeated in-person visits, improve patient safety, lower healthcare costs, and support more equitable access to medical services through remote monitoring, cloud-based data processing, clinician dashboards, and early warning alerts.

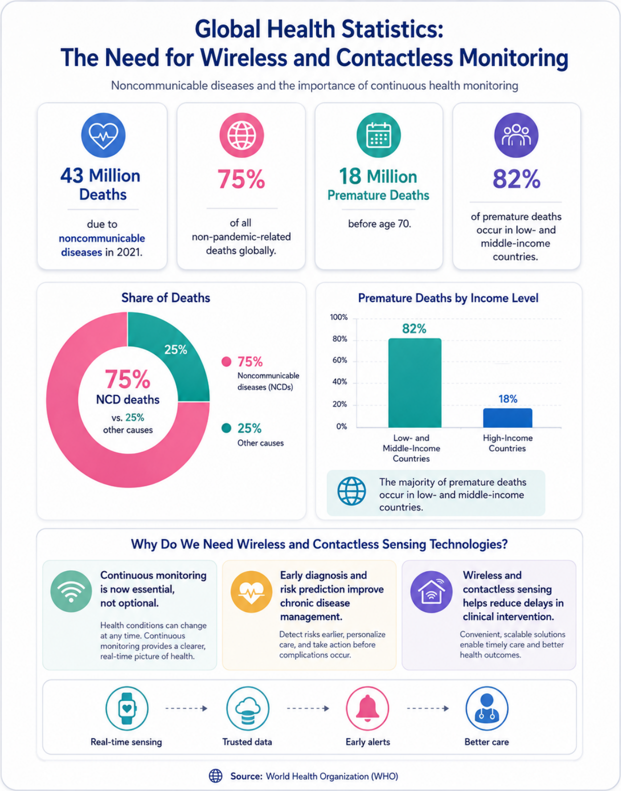


Figure 1. Global health statistics demonstrating the need for wireless and contactless sensing technologies in continuous healthcare monitoring.

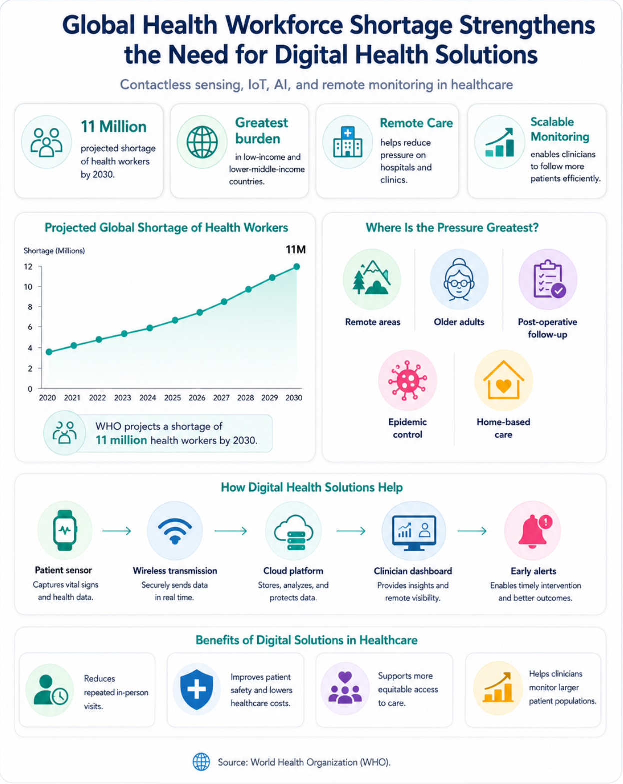


Figure 2. Projected healthcare workforce shortage and the importance of scalable digital-health solutions.

2. RELATED WORK

The advances in wireless and touchless sensing technologies have created a new form of thinking in newly born, personalized healthcare. These support technologies embrace less invasive ways of measuring a patient's physiological and psychological state, reducing patient discomfort and increasing diagnosis precision. Internet of Things, artificial intelligence, and advanced sensor techniques can make constant, real-time health checks possible, whether in challenging or resource-limited environments. This literature review aims to present a broad spectrum of studies, many of which focus on the use, issues, and opportunities that relate to the named technologies in different realms of healthcare. From pandemic response to modern wearable health monitors, these studies reflect a paradigm shift toward intelligent patient-centric healthcare systems.

In the research presented in [5], a novel touchless health and patient monitoring system integrating ultra-wideband radar and Internet of Things technologies was proposed to address the challenges of patient monitoring during pandemics such as COVID-19. The Internet of Things module, comprising a temperature sensor, heartbeat sensor, and pulse oximeter, enables real-time health parameter monitoring, with data stored in the cloud for access via mobile and web applications. Additionally, ultra-wideband radar facilitates touchless monitoring, reducing exposure risks for healthcare professionals. The system includes a health-assisting module that allows patients to interact with doctors through a mobile bot application called IOT FIT BOT. This comprehensive approach provides live health assistance and touchless monitoring, offering a promising solution for managing patient care during pandemic situations.

As discussed in [6], the COVID-19 pandemic has placed immense strain on healthcare systems globally due to the shortage of personal protective equipment and increased risk to medical professionals. To address these challenges, a contactless patient positioning system was developed to facilitate remote and contactless patient scanning. The system minimizes physical contact by employing automated calibration, positioning, and multi-view synthesis components. The novel Robust Dynamic Fusion algorithm enables accurate three-dimensional body modeling and multi-modal inference, allowing the system to operate across various sensor configurations without retraining, supporting scalability. Additionally, the multi-view synthesizer provides technicians with comprehensive visualization to verify patient positioning accuracy before scanning. Extensive experimentation on diverse datasets has validated the system's effectiveness, and it has already been positively received by hospitals and technicians during the pandemic, highlighting its potential for broader adoption globally.

In the analysis conducted in [7], a contactless operating room interface was developed to reduce contamination risks during surgical procedures by leveraging Leap Motion™ technology. A personalized automated classifier was employed to enhance gesture recognition accuracy, with training performed on a per-user basis. Thirty features, including finger and hand data, were computed, selected, and input into multiclass support vector machine and Naïve Bayes classifiers to recognize five gestures: hover, grab, click, one peak, and two peaks. The system achieved an overall gesture recognition accuracy of $99.58\% \pm 0.06$ with support vector machine and $98.74\% \pm 3.64$ with Naïve Bayes, highlighting the robustness of personal basis training. These findings demonstrate the potential of non-contact interfaces in improving operating room control systems with high precision and reliability.

Based on the work in [8], a non-contact system leveraging ordinary cameras and Internet technologies was proposed to detect employees' psychological vulnerability and predict potential risk behaviors during the COVID-19 pandemic. The system uses algorithms to analyze shallow blood changes captured from facial imagery, identifying physiological signs such as blood oxygen levels, blood pressure, respiration, and heart rate. The system provides real-time health scores and early warning interventions by mapping these physiological signs to psychological symptoms. Experimental results demonstrate the feasibility of this approach for continuous, non-contact psychological health monitoring, offering practical benefits such as rapid detection, real-time prediction, and long-term, extensive data tracking. This approach complements traditional psychological detection methods, making it a valuable tool for epidemic psychological prevention and assessment.

In the study referenced as [9], a simple and cost-effective sensor device was developed using an inductance coil connected to a high-frequency electric field generator. The sensor operates by placing a liquid sample in a plastic tube within the inductance coil, where the sample acts as the coil's core, altering the properties of the high-frequency electric current based on its conductivity, dielectric constant, magnetic properties, and capacitance. The resulting electric signal is a spectrum that can be analyzed using chemometric tools. The sensor demonstrated its ability to distinguish substances with varying physical and chemical properties, measure ion concentrations in aqueous solutions across a broad range with a linear response, quantify fat content in milk and cream samples with approximately 2% accuracy, and differentiate between bacterial and cell line cultures. The rapid and contactless measurements highlight the potential for a wide array of applications for this sensor system.

As outlined in [10], a prototype system was developed for monitoring cardiac activity using a microwave Doppler radar operating at a frequency of 24.05 GHz and an average output power of 7 mW. This non-contact system allows for remote monitoring without the need to remove clothing. The study also evaluated heart rate and heart rate variability during mental arithmetic and computer input tasks in a sample of seven participants with a mean age of 23.00 ± 0.82 years. The results demonstrated that the system accurately captured heart rate and heart rate variability, showing solid correlations with traditional electrocardiograph measurements, including heart rate ($r = 0.963$), low frequency (cross-correlation $= 0.76$), and low-frequency/high-frequency ratio (cross-correlation $= 0.73$). These findings highlight the system's potential for precise and noninvasive cardiac monitoring.

In the research presented in [11], a novel non-contact control system was developed to assist limb-disabled patients in managing essential tasks such as activating a nurse emergency call system, adjusting appliances like air conditioners, and controlling lights or televisions without manual intervention. The system integrates a wearable electroencephalogram device with non-contact dry electrodes to monitor patients' electroencephalogram signals. These signals are processed and converted into control commands via a signal processing system, enabling patients to interact with control icons displayed by a visual stimulus generator. This allows them to perform nurse calling and device control autonomously. Experimental results confirmed that the system effectively interprets electroencephalogram signals and translates them into desired control actions. It offers a practical framework to support hospital facilities and significantly reduce the burden on caregivers.

In the article denoted as [12], a contactless multi-intelligent wearable technology was introduced to enhance healthcare efficiency and monitor hard-to-heal wounds while minimizing infection risks. The system centers around a flexible artificial intelligence-guiding wearable sensor, which operates with a deep artificial neural network for chronic wound monitoring via short-range communication. Integrated into the SMART-WD bandage, the design utilizes pH-responsive poly(vinyl acrylic) gel PANI/Cu_2O nanoparticles to generate a current based on wound healing progress. A confusion matrix analysis from the deep artificial neural network training set revealed a 94.6% accuracy in classifying healing stages based on contactless pH-responsive voltage measurements. The bandage includes a chip-free capacitive Mxene/PTFE electret with adhesive acrylic inductance to resonate with the wearable antenna, achieving a sensitivity slope of -76 mV/pH under zero-current electrochemical conditions. Enhanced ion intercalation into the gel/PANI matrix under higher activation voltage increased current response exponentially. Healing stages were categorized into fast-curing, slow-curing, and no-curing, aiding in managing skin diseases treated with corticosteroids. This near-field sensing approach provides valuable insights for wound care, enabling data-driven decisions on treatment effectiveness and drug applications.

In the research presented in [13], a novel framework, MoD TRAP, was developed for heart rate tracking and preprocessing of motion-artifact-corrupted photoplethysmographic data. The framework integrates two signal decomposition techniques: variational mode decomposition for heart rate tracking and ensemble empirical mode decomposition combined with a neural network for preprocessing. Heart rate frequency was estimated from the mode functions of variational mode decomposition and tracked using an algorithm that exploits the photoplethysmographic signal's characteristic base heart rate frequency and harmonics. The heart-rate-synchronous signal component was reconstructed for motion artifact reduction using a template matching technique that leverages an autoencoder and a pre-trained multilayer feedforward neural network. Ensemble empirical mode decomposition with a long short-term memory binary classifier was employed to create and update reference photoplethysmographic templates. Experiments with the 2015 IEEE Signal Processing Cup Challenge database achieved an average absolute error of 1.02 and a percent absolute error of 0.86 compared to ground-truth heart rate for 22 subjects. For motion artifact reduction, wrist photoplethysmographic data from 30 subjects, including normal and cardiovascular patients, demonstrated a root mean squared error of 0.31 and a signal-to-noise-ratio improvement of 21.23 dB. These results highlight the MoD TRAP framework's significant advancements in heart rate tracking and motion artifact reduction compared to existing methods.

In the publication identified as [14], the integration of personal healthcare devices into automotive systems was examined to address the limitations faced by elderly individuals with chronic illnesses. While advancements in technology have enabled these individuals to use personal healthcare devices for continuous health monitoring, challenges remain in scenarios requiring mobility, such as driving to obtain treatment or medication. Current automotive systems lack interfaces for seamless interaction with healthcare devices. The study reviewed several standards for personal healthcare devices and proposed interfaces to connect these devices with automotive environments. Consideration was given to network interfaces within infotainment systems and their interconnection with healthcare platforms. This analysis proposed multiple implementations to support healthcare device standards in automotive systems, enabling continuous monitoring and improved accessibility for elderly individuals and those managing chronic conditions. This approach highlights the potential for enhancing mobility and healthcare accessibility by integrating healthcare technology into automotive environments.

As outlined in [15], a novel non-contact humidity sensor was developed using hyperbranched zwitterionic polymer to enhance biomedical monitoring and human-machine interaction. The sensor demonstrated rapid response and recovery times of 3 s/3 s and excellent repeatability across a humidity range of 11%–98% relative humidity. The superior performance was attributed to the precise regulation of molecular interactions within the polymer material. To further enhance sensitivity, LiCl was incorporated into the polymer to create a polymer/LiCl composite, resulting in an ultrafast response time of 0.2 s. The polymer/LiCl sensors exhibited robust long-term stability and strong resistance to interference, showcasing their potential for diverse applications. The sensors were successfully integrated into respiratory monitoring masks and gesture recognition keyboards by combining sensor arrays with control circuits for non-contact gesture detection. These findings demonstrate the significant potential of hyperbranched zwitterionic polymers as advanced humidity sensing materials, paving the way for innovative applications in biomedical monitoring and human-machine interaction technologies.

In the research presented in [16], a novel humidity-based human-machine interaction system was developed to address the limitations of traditional human-machine interaction technologies in detecting respiratory conditions. Unlike piezoresistive sensors, self-powered sensors, and visual or auditory receivers, which often lack reliability in breathing condition detection, this system leverages the stability and fast response of humidity signals conveyed by breathing. By integrating a humidity sensor with a graphene thermoacoustic device, the system enables respiratory signal monitoring and acoustic signal emission. This wearable device has significant applications in healthcare, serving as a prewarning system for patients with respiratory-related diseases exhibiting abnormal respiratory rates and functioning as an artificial throat device for aphasia patients. Fabricated using laser direct writing technology, the system is cost-effective, highly flexible, and scalable for mass production. Its non-contact and portable design highlights its potential for diverse applications in medical health and intelligent control systems.

As outlined in [17], the feasibility of using Kinect v2 motion capture devices for medical and healthcare applications was explored, focusing on addressing practical medical needs. The study developed three innovative applications: a non-contact respiration monitoring system designed to diagnose chronic obstructive pulmonary disease, a rehabilitation assistance system to support physiotherapy, and a three-dimensional skeletal motion viewer system. These applications demonstrate the potential of low-cost, noninvasive motion capture technology to enhance diagnostics and therapeutic practices in physiotherapy clinics, offering promising tools for improved patient care.

In the analysis conducted in [18], a self-powered humidity sensor was developed based on the moisture-directly triggered electricity generation effect, addressing the limitations of traditional moisture-sensitive systems that require external power sources. Silicon nanowire arrays served as the sensing element, providing ultrafast response of approximately 0.10 s/0.17 s and high sensitivity to humidity changes. The unique nanochannel structure, enlarged surface area, and superior electrical conductivity of silicon nanowire arrays enabled robust output voltage dependence on humidity levels across a broad detection range, namely 3.94 mV/1% for 50%–95% relative humidity and 1.13 mV/1% for 0%–50% relative humidity. The sensor was incorporated into an intelligent respiratory monitoring system capable of capturing diverse respiration patterns and distinguishing language commands. Additionally, a non-contact human-machine interface was designed using the sensor to minimize virus propagation and bacterial infection risks. The innovative self-powered design and advanced performance of the silicon nanowire sensor offer significant potential for future applications in wearable and integrated health monitoring platforms.

As discussed in [19], high-performance multifunctional humidity sensors based on heterostructure $Ti_3C_2T_x$ MXenes were developed to address the demands of wearable digital healthcare applications. The $Ti_3C_2T_x/SnO_2$ sensor exhibited significantly improved sensing capabilities compared to standard $Ti_3C_2T_x$ sensors, including a high response of 13.4, rapid response time of 2 s at 59% relative humidity, excellent repeatability, a wide detection range of 11%–97% relative humidity, and high selectivity to water. The enhanced performance was attributed to the synergistic effects of heterojunctions and complex impedance spectroscopy. These advancements make the $Ti_3C_2T_x/SnO_2$-based sensor suitable for real-time respiratory monitoring and non-contact human-machine interaction. This work highlights innovative strategies for designing humidity sensors capable of collecting biomedical signals and enabling advanced healthcare and interaction technologies.

As detailed in [20], a high-performance humidity sensor was developed using borophene-BC_2N heterostructures, prepared via in situ self-assembly under ultrasonic irradiation. These heterostructures were selected for their synergistic effects, significantly enhancing sensor performance compared to pristine borophene or BC_2N quantum dots. The sensor demonstrated remarkable capabilities, including a wide detection range of 11%–97% relative humidity, ultra-high sensitivity of 22,001% at 97% relative humidity, low hysteresis, fast response of 11.82 s, rapid recovery of 1.41 s, excellent repeatability, and long-term stability. This advanced sensor outperformed previous designs, achieving up to 100 times higher sensitivity at 97% relative humidity at room temperature. Its flexibility and high selectivity enable diverse applications, such as infant and patient diaper monitoring, wireless respiratory behavior tracking, speech recognition via exhalation humidity, and non-contact switches detecting fingertip humidity. These features highlight its potential in smart diapers, auxiliary voice systems, health monitoring, and non-contact human-machine interfaces, addressing infection risks while advancing the field of humidity sensors.

As discussed in [21], a self-adaptive pressure sensing platform was developed to provide reliable, noninvasive, continuous pulse and blood pressure monitoring, addressing the variability of pulse waves across individuals and over time. Inspired by traditional Chinese medicine pulse diagnosis, the system integrates a fully printed flexible pressure sensor array with an adaptive wristband-style pressure mechanism to identify optimal pulse signals. The platform captures detailed pulse features, including rate, width, and length, as well as traditional Chinese medicine-specific characteristics such as "Cun, Guan, Chi" positions and "floating, moderate, sinking" pulse types. Additionally, it uses a machine-learning-based linear regression model to accurately predict key blood pressure metrics such as systolic, diastolic, and mean arterial pressure. The platform demonstrated its capability for long-term, reliable pulse and blood pressure monitoring across multiple human subjects. This innovative design supports advancements in flexible sensing devices for personalized medicine and contributes to the digitalization of traditional Chinese medicine diagnostic methods, enhancing their integration into modern healthcare.

As outlined in [22], a high-performance flexible humidity sensor was developed using a tin disulfide nanoflowers/reduced graphene oxide nanohybrid powered by a poly(tetrafluoroethylene) triboelectric nanogenerator. The SnS_2/RGO humidity-sensitive film was screen-printed on a flexible PET substrate with gold interdigital electrodes. The integrated triboelectric nanogenerator, generating a peak-to-peak voltage of 500 V and a maximum output power of 378 μW, was combined with rectifier and stabilizer circuits to provide a steady voltage source for the sensor. The triboelectric humidity sensor exhibited excellent performance, including a steady output voltage range of 0–24 V, fast response/recovery times of 4 s/3 s at 33% relative humidity and 6 s/15 s at 97% relative humidity, a wide detection range of 0%–97% relative humidity, high stability, and ultralow power consumption of 29.78 μW. The sensor demonstrated potential applications in monitoring human respiration, cough frequency, and finger movements, highlighting its suitability for wearable electronics and personal healthcare. This work offers a novel approach to designing self-powered humidity sensors and explores the broader applications of triboelectric nanogenerators in self-powered electronic devices.

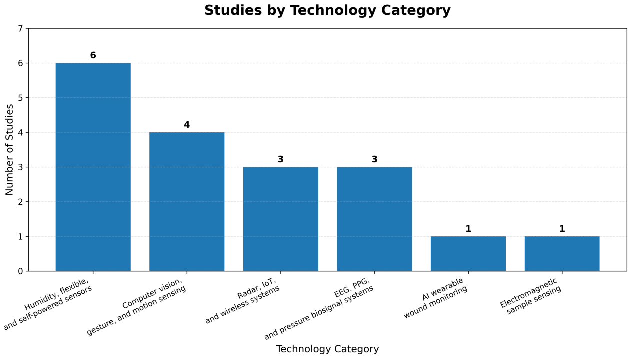
Table 1 summarizes the reviewed studies. Real-time monitoring is emphasized by employing Internet of Things and ultra-wideband radar; operating room interfaces are presented using Leap Motion™ technology, while inductance-based sensors detect bio-signals. These works highlight advancements in noninvasive and cost-effective healthcare services that help solve existing problems, such as epidemic control, telemonitoring of patients' conditions, and assistance for people with disabilities. The studies show possibilities for using the latest developments in sensing technologies, wearable devices, and learning algorithms to improve healthcare efficiency, promote accuracy, increase accessibility, and improve patient outcomes. Furthermore, self-energy-harvesting sensors and flexible substrates create the foundation for cost-effective and efficient implementation of technologies in both professional and domestic settings.

This paper shows that the reviewed reports indicate how contactless sensing technologies can lead to the evolution of personalized care. Through key problem-solving areas in signal processing, scalability, and user accessibility, such innovations enhance healthcare delivery and accommodate nearly everyone. However, some issues are yet to be solved to harness it, such as environmental interference and system integration issues. With the advance of these technologies, they can revolutionize patient care and provide solutions for clinicians and researchers in early diagnostics, continuous monitoring, and treatment. The adoption of newer technologies such as artificial intelligence and machine learning brings further attention to those trends that are instrumental in future healthcare. Figure 3 presents the distribution of the reviewed studies according to their dominant technological category. The chart shows that humidity-based, flexible, and self-powered sensors represent the largest group of reviewed technologies, with six studies focusing on respiratory monitoring, non-contact human–machine interaction, smart diapers, and wearable healthcare applications. This reflects the growing importance of flexible sensing materials and self-sustainable sensor platforms in modern biomedical monitoring. Computer vision, gesture-recognition, and motion-sensing systems form the second largest category, indicating their relevance in contactless clinical workflows, operating-room interfaces, rehabilitation support, and patient-positioning systems. Radar, Internet of Things, wireless platforms, and biosignal-based systems also appear prominently, demonstrating that contactless healthcare research is highly interdisciplinary and depends on the integration of sensing hardware, wireless communication, signal processing, and intelligent data interpretation.

Figure 4 summarizes the reviewed studies according to their primary healthcare application areas. The chart indicates that vital-sign and patient monitoring is the most dominant application, accounting for the largest number of studies. This confirms that the main research direction in wireless and contactless sensing is the continuous observation of physiological parameters such as respiration, heart rate, humidity variation, blood pressure, and patient movement. Other application areas, including clinical workflow support, operating-room control, mental-health monitoring, assistive care for disabled patients, wound monitoring, automotive healthcare, rehabilitation, and biological sample analysis, appear with smaller but important contributions. This distribution suggests that

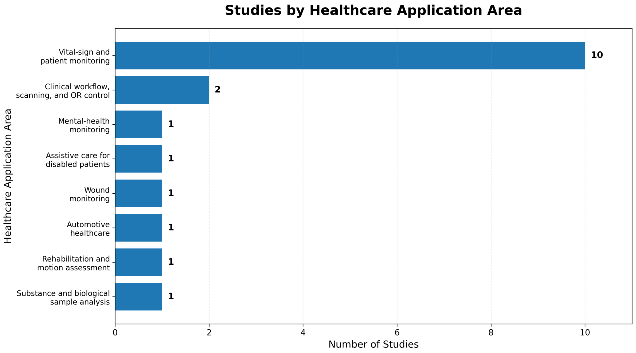
Table 1. Comparative Summary of Wireless and Contactless Sensing Technologies for Healthcare Applications

Study Reference	Technology/Focus	Key Contributions	Applications	Limitations/Challenges
[5]	IoT and UWB radar-based touchless monitoring	Proposed an integrated patient monitoring framework combining IoT sensors and ultra-wideband radar for real-time physiological data collection and remote access.	Pandemic patient monitoring, vital-sign tracking, cloud-based health supervision, and doctor–patient interaction through a mobile bot.	Requires reliable network connectivity, accurate radar signal processing, and secure cloud-based data management.
[6]	Contactless patient positioning system	Developed an automated contactless positioning framework using calibration, multi-view synthesis, and Robust Dynamic Fusion for accurate 3D body modeling.	Remote patient scanning, radiology workflow support, and reduced physical contact during infectious disease outbreaks.	Performance may depend on sensor configuration, environmental conditions, and integration with existing hospital imaging systems.
[7]	Leap Motion™ gesture-recognition interface	Introduced a personalized classifier using SVM and Naïve Bayes models to improve gesture recognition accuracy in operating rooms.	Contactless operating room control, surgical interface management, and contamination-risk reduction.	Requires user-specific training and may be affected by hand-position variability, lighting, and real-time calibration requirements.
[8]	Camera-based contactless physiological and psychological monitoring	Used facial imagery and Internet-based algorithms to estimate physiological indicators and map them to psychological stress symptoms.	Mental stress monitoring, psychological risk prediction, and early warning during epidemic situations.	Accuracy may be affected by lighting, facial movement, privacy concerns, and population-specific physiological variation.
[9]	High-frequency electromagnetic inductance-based sensor	Presented a simple contactless sensor capable of distinguishing liquid samples according to conductivity, dielectric properties, magnetic behavior, and capacitance.	Substance analysis, ion concentration measurement, fat-content estimation, and biological sample differentiation.	Requires chemometric analysis and further validation for complex biomedical samples and clinical environments.
[10]	Microwave Doppler radar for cardiac monitoring	Developed a non-contact radar system operating at 24.05 GHz for estimating heart rate and heart-rate variability with strong correlation to ECG measurements.	Remote cardiac monitoring, HRV assessment, and noninvasive physiological monitoring without removing clothing.	Small participant sample size and potential sensitivity to motion artifacts, body posture, and surrounding electromagnetic interference.
[11]	EEG-based non-contact control system	Designed a wearable EEG control system using non-contact dry electrodes to translate brain signals into control commands.	Assistance for limb-disabled patients, nurse-call activation, and control of home or hospital appliances.	Requires reliable EEG signal acquisition, user training, and robust artifact removal to ensure accurate command recognition.
[12]	FLEX-AI wearable sensor with smart wound dressing	Integrated AI-guided wearable sensing with smart wound dressing for contactless chronic wound monitoring and healing-stage classification.	Chronic wound care, infection control, tissue regeneration monitoring, and treatment-response evaluation.	Requires biocompatibility validation, stable near-field communication, and broader clinical testing across wound types.
[13]	MoD TRAP framework for PPG signal enhancement	Combined VMD, EEMD, autoencoder-based template matching, and LSTM classification to improve heart-rate tracking and reduce motion artifacts.	Personalized heart-rate tracking, wearable PPG monitoring, and artifact reduction in cardiovascular monitoring.	Computational complexity, dependence on high-quality training data, and challenges in real-time deployment on low-power wearable devices.
[14]	Personal healthcare devices integrated into automotive environments	Analyzed interfaces and standards for connecting personal healthcare devices with vehicle infotainment and healthcare platforms.	Continuous monitoring for elderly individuals, chronic disease management during mobility, and automotive health-support systems.	Requires interoperability among healthcare standards, automotive platforms, data security mechanisms, and user-friendly interfaces.
[15]	Hyperbranched zwitterionic polymer humidity sensor	Developed a fast-response humidity sensor with improved repeatability and sensitivity for respiratory and gesture-related monitoring.	Respiratory monitoring, non-contact human–machine interaction, smart masks, and gesture recognition keyboards.	May require further testing under variable humidity, temperature, and long-term wearable conditions.
[16]	Humidity-based human–machine interaction system with graphene	Integrated a humidity sensor with a graphene thermoacoustic device to monitor breathing and generate acoustic signals.	Respiratory abnormality detection, artificial throat applications, healthcare warning systems, and intelligent control.	Requires optimization for clinical reliability, speech clarity, wearable comfort, and large-scale manufacturing consistency.
[17]	Kinect v2 motion-capture-based non-contact sensing	Explored low-cost motion-capture technology for respiration monitoring, rehabilitation assistance, and skeletal motion visualization.	COPD assessment, physiotherapy support, rehabilitation monitoring, and noninvasive movement analysis.	Accuracy may be influenced by camera placement, patient movement, occlusion, and limited performance in uncontrolled environments.
[18]	Self-powered silicon nanowire humidity sensor	Introduced a moisture-electric-generation-based sensor with ultrafast response and recovery for self-powered respiratory monitoring.	Respiration pattern recognition, language command detection, wearable health monitoring, and non-contact interaction.	Requires further assessment of long-term stability, durability, and integration with wearable electronic platforms.
[19]	$Ti_3C_2T_x/SnO_2$ MXene heterostructure humidity sensor	Developed a flexible humidity sensor with fast response, wide detection range, high selectivity, and improved sensing performance.	Wearable healthcare monitoring, respiratory tracking, and non-contact human–machine interaction.	Material stability, scalability, and performance consistency under repeated bending and environmental exposure remain important issues.
[20]	Borophene-BC_2N quantum dot heterostructure humidity sensor	Presented an ultrasensitive flexible humidity sensor with wide detection range, low hysteresis, fast recovery, and long-term stability.	Smart diapers, wireless respiratory tracking, speech recognition, and non-contact switch control.	Further work is required to validate mass production, long-term biocompatibility, and real-world wearable performance.
[21]	Self-adaptive printed pressure sensing platform	Developed a flexible pressure sensor array with adaptive wristband pressurization for individualized pulse and blood pressure monitoring.	Pulse diagnostics, blood pressure estimation, personalized monitoring, and digitalization of traditional pulse diagnosis.	Requires extensive clinical validation across diverse populations and improved calibration for long-term blood pressure estimation.
[22]	SnS_2/RGO nanohybrid humidity sensor powered by TENG	Designed a self-powered flexible humidity sensor using a triboelectric nanogenerator to support low-power wearable sensing.	Respiration monitoring, cough-frequency detection, finger-movement tracking, and personal healthcare electronics.	Device performance may depend on mechanical energy availability, flexible packaging, and stable operation under daily-use conditions.



Based on literature-review studies [5]–[22].

Figure 3. Distribution of reviewed studies according to technology category.



Based on literature-review studies [5]–[22].

Figure 4. Distribution of reviewed studies according to healthcare application area.

although contactless sensing is currently concentrated around patient monitoring, its scope is expanding toward broader healthcare services that improve safety, accessibility, automation, and personalized medical decision-making.

3. CONCLUSION

The literature review shows that wireless and contactless sensing technology has a future in personalized healthcare. These systems are highly useful in providing a noninvasive, real-time manner of monitoring physiological and psychological parameters, dramatically improving patient comfort and the accuracy of clinical diagnosis. These enablers are Internet of Things-based systems, novel sensors, and artificial-intelligence-based algorithms that enhance and optimize patient experience and healthcare system efficiency. The use of such technologies covers present issues like outbreak control, shortage of resources and services, and remote patient interaction.

The main issues are still with interference and signal attenuation, data handling, and compatibility with the rest of the healthcare system. These matters make it imperative to develop these solutions to the next level, where they become more reliable and easily scalable. Filling these gaps will likely take more than biomedical engineering; it will also involve communications technology and computationally intensive sciences.

New improvements are expected in the aspects of using artificial intelligence and machine learning to produce predictive analysis, dynamic decision-making, and intelligent system actions. This means we are talking about more than just technology in healthcare; we are talking about accurate, anticipatory, and individualized healthcare. Advancements in self-sustainable power sources, flexible structures, and micro-sized devices also provide the basis for continued widespread usage in clinical and home healthcare applications.

In conclusion, wireless and contactless sensing technologies are the innovative front line for personalized healthcare, fulfilling gaps between access, effectiveness, and precision. When developed, these sophisticated systems have the potential to revolutionize patient management and the practice of medicine in the international territory as enhanced technical solutions become more open and effective. The discoveries entail that if research and development are taken further, then what has been developed might represent a new face for modern medicine.

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