

concentrations. For example, SWCNTs (Sultana *et al.*, 2023) exhibit unique optical properties that change in the presence of specific biomolecules, making them suitable for optical biosensors (Sultana *et al.*, 2023; Budhathoki-Uprety *et al.*, 2021; Budhathoki-Uprety *et al.*, 2020).

Electrochemical sensors have also gained prominence, particularly in the detection of metabolic diseases like diabetes, where continuous monitoring of glucose levels is crucial. Advances in microfluidics have enabled the integration of these sensors into wearable devices, allowing for real-time monitoring of physiological parameters (Budhathoki-Uprety *et al.*, 2021).

Moreover, the integration of artificial intelligence and machine learning with sensor technology has opened new avenues for predictive analytics in healthcare. These smart sensors can analyze complex biological data, identify patterns, and predict disease onset much before traditional diagnostic methods to individual patients (Budhathoki-Uprety *et al.*, 2020; Michaelson *et al.*, 2018). This precision ensures that treatments are not only more effective but also significantly reduce the likelihood of adverse effects, marking a paradigm shift from one-size-fits-all approaches to highly targeted, patient-centric therapies (Salem *et al.*, 2023). The continuous monitoring of health parameters is another domain where CNT sensors shine (Sultana *et al.*, 2023). Their real-time data acquisition capabilities enable the tracking of biomolecular changes over time, providing clinicians with a dynamic understanding of a patient's health status. This continuous monitoring is particularly impactful in chronic disease management, allowing for proactive adjustments to treatment plans and enhancing overall disease control (Dewey *et al.*, 2023).

3. Applications in early disease detection

The application of advanced sensors in early disease detection spans various domains. Cancer, one of the leading causes of death worldwide, is a primary focus area. Sensors capable of detecting cancer biomarkers at early stages have been developed, potentially transforming cancer prognosis and treatment. For instance, sensors detecting specific proteins or genetic markers associated with certain cancers can facilitate early intervention, improving patient outcomes (Salem *et al.*, 2023).

Infectious diseases, particularly in the context of global pandemics, are another area where sensors play a crucial role. Rapid diagnostic tests based on sensor technologies have been pivotal in managing and controlling the spread of diseases like Covid-19. These tests can quickly and accurately identify viral or bacterial infections, enabling timely isolation and treatment (Dawn *et al.*, 2023; Dewey *et al.*, 2023; Sultana *et al.*, 2023).

Additionally, sensors are instrumental in the management of chronic diseases. Wearable sensors that continuously monitor vital parameters like blood glucose, heart rate, and oxygen saturation provide valuable insights into the patient's health status, allowing for early detection of anomalies that could indicate disease progression or complications.

4. Challenges and future directions

Despite the significant advancements, there are challenges in the widespread adoption of sensor technologies for early disease detection. Issues related to sensitivity, specificity, and the ability to operate in complex biological environments are ongoing research areas. Additionally, the integration of these technologies into healthcare systems poses logistical and economic challenges (Budhathoki-Uprety *et al.*, 2023).

The future of sensor technology in early disease detection is promising. Research is moving towards the development of multiplexed sensors capable of detecting multiple biomarkers simultaneously, offering a more comprehensive diagnostic tool. The miniaturization of sensors and their integration with mobile technology will also enhance accessibility, allowing for point-of-care diagnostics and personalized medicine (Dewey *et al.*, 2021).

Furthermore, the convergence of sensor technology with other emerging fields like telemedicine and digital health platforms could redefine healthcare delivery (Ashraful *et al.*, 2023; Al-Amin *et al.*, 2020; Al-Amin *et al.*, 2021), making it more patient-centric and efficient (Dewey *et al.*, 2021).

5. Conclusion

The role of sensors in early disease detection is invaluable and has the potential to transform healthcare. As technology advances, sensors will become more sophisticated, offering higher accuracy, sensitivity, and user-friendliness. The integration of these technologies into clinical practice will undoubtedly enhance disease

management, reduce healthcare costs, and improve patient outcomes. Continuous research and collaboration across disciplines are essential to realize the full potential of sensor technologies in early disease detection landscape of electronic devices. Picture a not-so-distant future where carbon nanotubes take center stage, playing a pivotal role in shaping the very fabric of the next generation of sensing technologies.

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