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From smart soles to green goals, interlacing sustainable innovations in the age of smart health: An exploratory search

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Abstract. Health goes beyond the mere absence of illness. It's arguably a state that encompasses a whole spectrum of physical, social, and mental well-being. It involves not only curing sickness but also promoting healthy lifestyles, behaviors, and environments that enable individuals to thrive. Health interventions can be formalized through medicine, but they can also take on a broader spectrum of approaches, including prevention, early detection, and management of diseases. By acknowledging this broader vision of health, we can see that it influences various aspects of our lives, including our work, education, relationships, food, clothes, and recreational activities. It also impacts our communities and cultures, affecting social norms, policies, and practices that shape our health outcomes. Therefore, health is not just an individual concern but also a collective one. Furthermore, the integration of health into technological practices can have a significant impact on our well-being. It can facilitate access to health information, resources, and services, enable remote monitoring and diagnosis, and enhance communication and social support networks.

Introduction

In an era where technology and health converge, the paradigm of smart health not only reshapes how we monitor well-being but also holds the potential to redefine our relationship with the environment. Smart health technologies, in addition to revolutionizing well-being management, present auspicious avenues for ameliorating our environmental footprint.

Concurrently, the urgency of mitigating climate change compels us to explore innovative solutions that optimize resource consumption and minimize environmental impact. This article delves into the intricate nexus of these two critical domains, exploring how smart health advancements can foster both individual well-being and environmental responsibility.

This article encapsulates a journey into the synergy between cutting-edge healthcare technologies and a commitment to environmental sustainability. This exploratory search navigates through the intricate tapestry of interconnected themes. We will first delve into the profound connections between sustainability practices and individual well-being. From exploring how smart shoes contribute to holistic health monitoring to the impact of programming languages on carbon emissions, we dissect the intricate threads that weave together a narrative of interconnected health and environmental consciousness.

Literature Study

Zahid et al. [1] responded to the primary weakness of Body Sensors Area Networks (BSNs) which is energy consumption which is due to their small size and limited lifetime batteries, they wrote a paper that presents two contributions. First, they propose an adaptive duty-cycle optimization algorithm (ADO) that enhances the devices' active time by taking into consideration the exact power level that saves more energy, unlike traditional methods that increase the sleep period. Second, they propose a joint Sustainable and Green smart-health framework. They conducted a thorough experimental and theoretical analysis through real-time data. The results showed that the algorithm enhances energy and reliability savings by 36.54% and 24.43%, respectively. Therefore, they concluded that the algorithm is more promising for energy-limited sensor devices in healthcare-connected platforms.

Abdellatif et al. [2] have proposed an architecture that uses wireless technologies and sensors to connect patients with medical healthcare. This framework differs from previous work in this field by using various wireless networks to optimize medical data delivery. The team aims to reduce the size of transmitted data while maintaining reliable real-time healthcare services. They have developed an energy-efficient s-Health system by incorporating wireless network components with application characteristics and using the spectrum across multiple radio access technologies to fulfill the applications' Quality of Service (QoS). The proposed MEC-based system architecture meets all s-Health requirements. The team has used intelligent data processing techniques at the network edge to achieve this. They have also introduced some edge computing techniques, such as adaptive in-network compression, event detection, and network-aware optimization, which enable MEC-based system architecture to fulfill all s-Health requirements. In addition, the team has discussed the challenges and open issues for utilizing the MEC paradigm in s-Health. This includes the use of cooperative edges to improve energy and spectrum efficiency, as well as the need and benefit of combining heterogeneous data sources at the edge.

D. Laxma Reddy et al. [4] mainly focused on finding the best Cluster Head for an energy-efficient routing protocol in Wireless Sensor Networks (WSN). The paper proposes a new hybrid algorithm called Ant Colony Optimization (ACO) integrated Glowworm Swarm Optimization (GSO) approach (ACI-GSO) as a solution for Cluster Head Selection (CHS). The main objective of CHS is to reduce the distance between the selected Cluster Head nodes. To achieve this, the fitness function uses multiple objectives such as distance, delay, and energy. Finally, the proposed work was evaluated and proved to be more effective compared to other conventional methods.

Intertwining Sustainability and Well-being

In this chapter, we delve into the intricate connections between sustainability and well-being, exploring how sustainable innovations can significantly impact and promote overall health and wellness. By examining the interplay between sustainable practices and well-being, we aim to uncover the profound implications of sustainability on fostering a healthier and more environmentally conscious future. For example, hospitals have started installing solar energy systems to meet part of their energy needs. Others have implemented waste management programs to minimize their impact on the environment.

A. Sustainable Waste Management Optimization

Sustainable waste management (SWM) optimization in the context of smart health involves leveraging technology to minimize waste generation, maximize resource efficiency, and reduce environmental impact within healthcare settings. Here's how it works:

1) Reducing Medical Waste:

Smart health technologies can help streamline healthcare processes, leading to reduced medical waste generation. For example, digital health records and telemedicine platforms eliminate the need for paper-based records and unnecessary in-person visits, thereby reducing paper and plastic waste.

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2) Optimizing Resource Utilization:

Smart sensors and IoT devices can monitor resource usage in healthcare facilities, such as energy, water, and medical supplies. By analyzing real-time data, healthcare providers can identify inefficiencies and implement strategies to optimize resource utilization, thereby reducing waste [1]. In 2017, the Republic of Türkiye's Ministry of Environment, Urbanization, and Climate Change launched the "Zero Waste Project." The project aims to prevent waste generation, reduce waste, recycle waste at its source, prevent wastage, and utilize natural resources more efficiently [5].

3) Recycling and Reuse:

Smart health technologies can facilitate the recycling and reuse [19] of medical equipment and supplies. For instance, smart inventory management systems can track the usage of medical supplies and identify items that can be recycled or sterilized for reuse, reducing the need for single-use items.

4) Waste Segregation and Disposal:

Smart waste management systems can automate the segregation and disposal of different types of waste in healthcare facilities. By using sensors and AI algorithms, these systems can identify recyclable, hazardous [18], and non-recyclable waste, ensuring proper disposal and minimizing environmental contamination.

Fig 1. Planetary Health pathway

The Green Grid of Health with Smart Technologies

We'll break down the intricate connections between smart health and sustainability, demystifying the technologies and highlighting their potential to revolutionize both our well-being and the health of our planet. In this context, it is evident that green technologies have been implemented to enhance the quality of healthcare, or at least support for energy consumption measurement should be provided [12]. Hospitals are now utilizing air quality monitoring systems to ensure a healthy environment for both patients and staff. Additionally, energy-efficient medical equipment is being used to reduce energy consumption and costs. There are many other initiatives as well [7][8].

A. Harvesting the Planet for a healthier life

1) How Smart Shoes are Paving the Way for a More Active and Earth-Conscious Future

• ***Promoting Physical Activity:*** Embedded sensors can track steps, distance, and calories burned, motivating users to embrace healthier lifestyles and reduce reliance on carbon-heavy transportation.

• ***Encouraging Sustainable Choices:*** Gamified fitness apps linked to smart shoes can incentivize walking and cycling over car travel, reducing individual carbon footprints [12].

• ***Generating Green Energy:*** Kinetic energy from footsteps can be harvested to power the shoes themselves or even contribute to a microgrid for other smart health devices, eliminating reliance on batteries [8][17]. Also, wave generators and turnstiles are innovative ways to generate renewable and sustainable energy. Wave generators use natural resources like oceans' wave movement, while turnstiles [25] generate electricity each time someone passes through them, they are usually put in a population-dense area.

2) Solar Panels as a Sustainable Powerhouse:

• ***Green Energy Source:*** Embedded solar panels can power healthcare facilities (Points Of Care) and health devices, minimizing dependence on conventional electricity [11], and reducing greenhouse gas emissions.

• ***Decentralized Power:*** Distributed solar energy collection in smart shoes and wearable devices lowers reliance on centralized grids, increasing resilience and sustainability.

• ***Personal Empowerment***: Individuals gain autonomy over their energy needs, promoting environmental consciousness and fostering a sense of self-reliance.

In other words, smart shoes [17] play a multifaceted role in promoting physical activity, tracking environmental data, and contributing to sustainable transportation choices. Additionally, smart panels offer a renewable energy source for smart health monitoring systems, with the challenge lying in finding the right balance between device performance and energy consumption through thoughtful optimization strategies.

B. Invisible Footprint: Green Programming for a Healthier Planet

The digital world might seem intangible, but the lines between its code and our planet's health are not. Programming languages, software architectures, and middleware, though seemingly technical aspects of software development, hold hidden implications for CO2 emissions and ultimately, the well-being of our planet and its inhabitants [1].

1) The Impact on Planetary and Human Health:

• ***Climate Change:*** Increased CO2 emissions contribute to global warming, rising sea levels, extreme weather events, and ecosystem disruption, impacting food security, water resources, and public health.

• ***Air Pollution:*** Data centers rely on energy sources that often result in air pollution, exacerbating respiratory illnesses and cardiovascular diseases.

• ***Mental and Social Impacts:*** The relationship between our health and that of the planet is very tight, any disturbance in the planet's ecosystem is a disturbance to humanity, for instance, Climate change and its consequences pose mental health [16] challenges as well as displacement and social unrest, creating a chain reaction of suffering.

Fig 2. Illustration of Green Technologies impact

• ***Data Centers and Cloud Services Energy Consumption:*** Large-scale data centers that host software applications and cloud services consume significant amounts of energy. Inefficiently designed software can contribute to higher energy needs in data centers, amplifying the environmental footprint and impacting planetary health.

• ***Electronic Waste (E-Waste) & Short Lifecycle:*** Poorly designed software may lead to faster hardware obsolescence, contributing to the generation of e-waste. E-waste disposal has environmental consequences, with improper disposal methods leading to soil and water pollution, negatively affecting planetary health.

2) Programming languages for a sustainable future:

Different programming languages have varying levels of energy efficiency. For instance, languages that demand more computational resources may contribute to higher energy consumption during program execution. The choice of programming language affects the energy requirements of software systems and subsequently influences CO2 emissions.

• ***Software Architectures:*** The design and architecture of software systems determine how efficiently resources, including processing power and memory, are utilized. Poorly optimized software architectures can result in excessive resource usage, leading to higher energy consumption and increased CO2 emissions [1][3].

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• ***Middleware and communication efficiency(Green middleware):*** Opting for lightweight, energy-efficient middleware solutions can streamline data communication and management while maximizing sustainability. Inefficient middleware can lead to higher data transfer loads, requiring more energy for communication processes and contributing to increased CO2 emissions [2][3].

• ***Code-Level Awareness:*** Educating developers about the environmental impact of their code choice.

• ***Algorithmic Efficiency:*** Optimizing algorithms for reduced processing power and minimizing unnecessary computations can significantly decrease energy consumption [2] [3][4].

• ***Lightweight Architectures****:* Choosing leaner frameworks, optimizing server usage, and minimizing geographic distribution can help reduce the carbon footprint of software systems [3].

By acknowledging the link between programming and planetary health, we can weave a new narrative. By optimizing code, architectures, and middleware, we can rewrite our digital footprint and contribute to a future where technology complements, not threatens, the well-being of our planet and its inhabitants(Global Health). Let's remember, that every line of code has the potential to leave a mark, not just on a screen, but on the very fabric of our planet's health.

C. The Tradeoff of Performance vs. Energy Consumption

1) Optimizing the Performance-Energy Trade-off:

The quest for powerful smart devices often comes at the cost of high energy consumption. However, several strategies can strike a balance:

• ***Sensor Optimization:*** Employing energy-efficient sensors and utilizing them strategically can significantly reduce power consumption without compromising data accuracy.

• ***Low-Power Processors:*** Implementing specialized, low-power processors specifically designed for wearables can further enhance energy efficiency.

• ***Cloud-Based Processing:*** Offloading data processing to the cloud reduces on-device energy needs, enabling more powerful features while extending battery life.

• ***Adaptive Algorithms:*** Developing algorithms that adjust processing power based on activity level can optimize performance while ensuring efficient energy use [2].

2) Addressing Concerns about Smart Health Device Electromagnetic Frequency Radiation

Smart devices, including wearables, emit non-ionizing radiation in the radiofrequency (RF) range. Unlike ionizing radiation (e.g., X-rays) which can damage DNA, RF radiation is generally considered safe at low levels. However, concerns remain about the potential long-term health effects of chronic exposure, particularly with the increasing number of devices we interact with daily.

• ***Safety Standards and Research:*** International safety guidelines, such as those set by the International Commission on Non-Ionizing Radiation Protection (ICNIRP), exist to limit exposure to RF radiation. Device manufacturers must adhere to these standards, ensuring emissions remain within safe thresholds. Ongoing research continues to investigate the potential health effects of chronic RF exposure. While some studies haven't found conclusive evidence of harm, others suggest a weak link between certain types of RF radiation and increased risk of certain cancers, like brain tumors. However, it's important to note that these studies are often complex, with confounding factors and limitations, making it difficult to establish definitive causal relationships.

• ***Exposure Levels and Health Effects:*** Prolonged exposure to electromagnetic frequency (EMF) radiation from smart devices, including wearables, raises concerns about its impact on human health. While EMF is a fundamental aspect of technology, addressing concerns involves understanding potential risks associated with extended exposure. Some studies suggest a possible link between long-term exposure to EMF radiation and health issues such as headaches, sleep

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disturbances, and potential implications for fertility. Ongoing research aims to clarify these potential health effects and establish clear causal relationships.

• ***Navigating the Uncertainty:*** While uncertainty persists, responsible use of smart devices can help mitigate potential risks like minimizing Exposure; and limit the time spent close to the device, particularly when it's actively transmitting data. For example, don't sleep with your phone under your pillow or keep it directly against your body for extended periods. Opt for Airplane Mode; When not in use, turn off wireless features like Bluetooth and Wi-Fi to minimize unnecessary exposure. Choose Eco-Friendly Devices; Some devices offer lower-power modes or settings that can reduce radiation emissions. Stay Informed; Follow reputable sources, like international health organizations, for updates on research findings and safety recommendations.

• ***Vulnerability and Specific Absorption Rate(SAR):*** SAR measures the rate at which the body absorbs radiofrequency (RF) energy from a device. Regulatory bodies set SAR limits to prevent excessive RF energy absorption and minimize potential health risks. Also, vulnerable populations, such as pregnant individuals and children, are of particular concern due to potential sensitivity to radiation. Recognizing the need for caution, especially for those more susceptible, underscores the importance of safety standards.

Discussion

In a tapestry woven from the threads of science, technology, and environmental consciousness, our article has explored the intricate connections between individual well-being, sustainable practices, and the health of our planet. In exploring the realm of smart health and sustainable innovations, we've delved into a diverse array of topics. From the foundational concerns surrounding electromagnetic frequency radiation emitted by smart devices to the intricate interplay between programming languages, software architectures, and CO_2 emissions, the journey has been comprehensive. Our study extended to the pivotal role of smart shoes in promoting physical activity and sustainable transportation choices, not forgetting their potential to generate green energy [11]. However, the reviewed literature showcases commendable efforts to address key challenges in smart health systems, particularly focusing on energy consumption efficiency and sustainable energy. While each work contributes significantly to the field, further collaborative research could explore synergies between these approaches, potentially offering holistic solutions for the evolving landscape of smart health systems. For instance, a combination of these approaches applied for a Wearable Area Sensors Network, that can rely on self-energy generation from human motion would be the most efficient, like energy-harvesting shoes.

Conclusion and Future Perspective

Our exploration of the intricate nexus between smart health technologies, green solutions, and language processing reveals a promising avenue toward a sustainable future. Intertwined threads of smart health innovation, from nuanced personal well-being monitoring to the interplay of connectivity protocols, frequency radiations, and language processing, unveil a tapestry of profound interconnectedness. The symbiotic relationship between these technological advancements and environmental stewardship offers a blueprint for a future where technological progress and ecological responsibility coexist harmoniously.

Future work may include a novel approach that follows this study to implement a greener and more sustainable Smart Health Monitoring System that monitors both human and planetary health.

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