Integrating Nanotechnology into the Internet of Things

2022-01-08

The internet of things (IoT) paradigm has long been considered a key incentive to the Fourth Industrial Revolution with the potential to transform the way we live our lives. Yet its impact promises to be enhanced further through the integration of nanotechnology.

The IoT is a system of interrelated physical objects embedded with sensors, antennas, processors, software, and other technologies to enable relevant data exchange over the internet. From pills to guided missiles, the scope of these devices is vast and looks set to grow; predictions for the number of IoT-connected devices in 2025 peak at 75 billion, with tens or possibly hundreds of zettabytes of generated data.

Facilitating such substantial predictions is the development of enabling technologies (including cloud computing and big data analytics) and various communication modes, termed IoT protocols. These protocols enable data exchange between the endpoint devices, such as sensors and the next piece of hardware in the connected environment. They include Bluetooth, Wi-Fi, ZigBee, and Near field communication (NFC) for short distances, low-power wide-area (LPWA) and 5G for long distances.

Arguably, one of the most fascinating developments lies in the integration of nanotechnology. This promises to extend the IoT concept to its fullest through nanodevices and give rise to a whole new IoT derivative, the internet of Nano-Things (IoNT).

Nanodevices

Adopting nanomaterials within IoT devices can make use of their exceptionable properties to increase the functionality, energy efficiency and accuracy of the devices while reducing their size. Nanoantennas, nanoprocessors and nanobatteries are all examples of IoT nanodevices currently being utilized or developed, but within IoT endpoints, nanodevices have found the most use as nanosensors.

Nanosensors

IoT sensors must monitor specific phenomena in sensing environments to provide relevant data for subsequent analysis. Nanosensors use a broad range of nanomaterials to achieve this and are capable of physical, chemical, and biological monitoring.

For example, Tang et al. (2019) developed a flexible nanowire-based sensor for real-time ammonia (NH_3) monitoring. The sensor, developed to be used within a watch-type device, displayed a lower detection limit and faster response time than traditional NH_3 sensors primarily due to the nanowires' extremely high surface area to volume ratio.

The remarkably low power consumption (as low as 3μW) and scalable soft lithography fabrication technique further support how nanomaterials can act to enhance IoT sensors realistically.

Similar nano-based advantages have been seen for non-invasive biosensors for continuous blood glucose monitoring and for chemical, microbe and other analyte monitoring in drinking water.

Nanoantennas

IoT antennas are responsible for the wireless communication of IoT devices by receiving, decoding and transmitting information via various wave types. Nanoantennas, often graphene-based, primarily achieve such a function by radiating in the terahertz frequency band.

They are predictably much smaller than traditional antennas and can even be consolidated with nanosensors by using carbon nanotubes, which can both sense and signal.

Another particularly exciting nano-based advantage could lie in the fabrication technique. Researchers at the Drexel University have developed a titanium carbide nanoantenna that can be sprayed directly onto any object, rigid or flexible, in a simple one-step process without adding any weight or circuitry, enabling any object to quickly become a smart IoT device.

Nanoprocessors

An IoT processor must process data received from the IoT endpoints by performing suitable calculations. They are primarily made from silicon and consist of millions, often billions, of transistors acting as binary switches within collections of gates that mimic logic functions.

Nanoprocessors remain very much in the laboratory, with a team of MIT engineers developing the first programmable carbon nanotube processor only a few years ago in 2019. Consisting of just 14000 transistors, realizing the greater efficiencies and speeds of carbon nanotubes in such a function may still be many years more.

Nanobatteries

Predictably, a wireless system of smart devices has significant power demands suited to long-lifetime, high energy density and rechargeable batteries. Lithium-ion variants are currently the most popular.

Nanobatteries employ nanomaterials in the electrodes or membrane to decrease self-discharge rates, increase energy density, and decrease charging times.

Soliman et al. (2021) found that carbon nanotubes, lithium titanate oxide nanoparticles, and germanium nanowires are all examples of nanomaterials that have been successfully utilised to this effect.

Internet of Nano-Things

Incorporating all or some of these nanodevices into the existing IoT concept is considered to give rise to the Internet of Nano-Things. Although commonly described as just a nanoscale version of the IoT, the implications of the IoNT go far beyond what is suggested by the simple differentiation.

The advantages of nanodevices, whether it is the enhanced sensitivity of nanosensors or the increased energy density of nanobatteries, allow a new level of sophistication to the IoT paradigm and facilitate its applicability in ever-increasing applications.

IoNT and IoT Challenges

With billions of sensors collecting unprecedented amounts of confidential data, privacy and security concerns are critical barriers to widespread uptake. Suitable levels of encryption, cyber security protocols, and authentication are all required before the necessary confidence in the IoT and IoNT can be achieved.

Such a vast number of sensors also raises power supply concerns, especially considering the reliance of current battery technology on lithium.

Arm, the UK chipmaker, highlighted this problem by stating that satisfying battery demands for the predicted IoT and IoNT adoption would require tripling the worldwide annual lithium production.

IoNT and IoT Future Research

To address the remaining challenges facing the IoT and IoNT, extraordinary amounts of research are already underway. From multi-layer blockchain security models to graphene-based switched-beam nanoantennas, future research promises to be varied and plentiful.

A fascinating area tackling the issues surrounding sensor and nanosensor power supplies may have found its solution in energy harvesting, where energy is derived from external sources and then converted into useful electrical energy.

Once again, the future of this solution is likely to be firmly rooted in nanotechnology. Phillips, (2021) showed that, among other examples, nanowires in piezoelectric nanogenerators and quantum dots in thermoelectric generators could replace IoT and IoNT endpoint batteries altogether, enabling the tremendous uptake of the technology while being environmentally friendly and economically viable.

Read the original article on AZoNano.