Artificial Intelligence Powers Record-breaking All-in-one Miniature Spectrometers

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Using Artificial Intelligence (AI) to replace optical and mechanical components, researchers have designed a tiny spectrometer that breaks all current resolution records.

We see light and colours around us every day. However, to analyse the information it carries, we must analyse light using spectrometers, in the lab. These devices detect sparkles and substances that our eyes would otherwise not notice.

Now, an international team of researchers, including the University of Cambridge, have designed a miniaturised spectrometer that breaks all current resolution records, and does so in a much smaller package, thanks to computational programmes and artificial intelligence.

The new miniaturised devices could be used in a broad range of sectors, from checking the quality of food to analysing starlight or detecting faint clues of life in outer space.
The results are reported in the journal Science.

Traditionally, spectrometers rely on bulky components to filter and disperse light. Modern approaches simplify these components to shrink footprints, but still suffer from limited resolution and bandwidth. Additionally, traditional spectrometers are heavy and take up extraordinary amounts of space, which limits their applications in portable and mobile devices.

To tackle these problems, and shrink the size of the system, researchers have coupled layered materials with artificial intelligence algorithms. The result is an all-in-one spectrometer thousands of times smaller than current commercial systems. At the same time, it offers performance comparable to benchtop systems. In other words, these new

spectrometers will provide portable alternatives to uncover otherwise invisible information, without even going into the lab.

“We eliminate the need for detector arrays, dispersive components, and filters. It’s an all-in-one, miniaturised device that could revolutionise this field,” said Dr Hoon Hahn Yoon, from Aalto University in Finland, first author of the paper. This spectrometer-on-chip technology is expected to offer high performance and new usability across science and industry.

The detector uses van der Waals heterostructures – a ‘sandwich’ of different ingredients, including graphene, molybdenum disulfide, and tungsten diselenide. Different combinations of material components enable light detection beyond the visible spectrum, as far as the near-infrared region. This means the spectrometer detects more than just colour, enabling applications such as chemical analysis and night vision.

“We detect a continuum spectrum of light, opening a world of possibilities in a myriad of markets,” said Yoon. “Exploring other material combinations could uncover further functionalities, including even broader hyperspectral detection and improved resolution.”

Artificial intelligence is a key aspect of these devices, commonly called ‘computational’ spectrometers. This technology compensates for the inherent noise increase that inevitably occurs when the optical component is wholly removed.

“We were able to use mathematical algorithms to successfully reconstruct the signals and spectra, it’s a profound and transformative technological leap,” said lead author Professor Zhipei Sun, also from Aalto University, and a former member of Cambridge’s Department of Engineering. “The current design is just a proof-of-concept. More advanced algorithms, as well as different combinations of materials, could soon provide even better miniaturised spectrometers.”

Spectrometers are used for toxin detection in food and cosmetics, cancer imaging, and in spacecraft – including the James Webb Space Telescope. And they will soon become more

common thanks to the development and advancement of technologies such as the Internet of Things and Industry 4.0.

The detection of light – and the full analysis of spectroscopic information – has applications in sensing, surveillance, smart agriculture, and more. Among the most promising applications for miniaturised spectrometers are chemical and biochemical analysis, thanks to the capabilities of the devices to detect light in the infrared wavelength range.

The new devices could be incorporated into instruments like drones, mobile phones, and lab-on-a-chip platforms, which can carry out several experiments in a single integrated circuit. The latter also opens up opportunities in healthcare. In this field, spectrometers and light-detectors are already key components of imaging and diagnostic systems – the new miniaturised devices could enable the simultaneous visualisation and detection of 'chemical fingerprints', leading to possibilities in the biomedical area.

"Our miniaturised spectrometers offer high spatial and spectral resolution at the micrometre and nanometre scales, which is particularly exciting for responsive bio-implants and innovative imaging techniques," said co-author Professor Tawfique Hasan, from the Cambridge Graphene Centre.

This technology has huge potential for scalability and integration, thanks to its compatibility with well-established industrial processes. It could open up the future for the next generation of smartphone cameras that evolve into hyperspectral cameras that conventional colour cameras cannot do. Researchers hope their contribution is a stepping stone towards the development of more advanced computational spectrometers, with record-breaking accuracy and resolution. This example, they say, is just the first of many.

Read the original article on University of Cambridge.