Tech Xplore

Enabling 'internet of photonic things' with miniature sensors

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A team of researchers at Washington University in St. Louis is the first to successfully record environmental data using a wireless photonic sensor resonator with a whispering-gallery-mode (WGM) architecture.

The photonic sensors recorded data during the spring of 2017 under two scenarios: one was a real-time measurement of air temperature over 12 hours, and the other was an aerial mapping of temperature distribution with a sensor mounted on a drone in a St. Louis city park. Both measurements were accompanied by a commercial thermometer with a Bluetooth connection for comparison purposes. The data from the two compared very favorably.

In the grand world of the "internet of things" (IoT), there are vast numbers of spatially distributed wireless sensors predominately based on electronics. These devices often are hampered by electromagnetic interference, such as disturbed audio or visual signals caused by a low-flying airplane and a kitchen grinder causing unwanted noise on a radio.

But optical sensors are "immune to electromagnetical interference and can provide a significant advantage in harsh environments," said Lan Yang, the Edwin H. & Florence G. Skinner Professor of Electrical & Systems Engineering in the School of Engineering & Applied Science, who led the study from which the findings were published Sept. 5 in *Light: Science and Applications*.

"Optical sensors based on resonators show small footprints, extreme sensitivity and a number of functionalities, all of which lend capability and flexibility to wireless sensors," Yang said. "Our work could pave the way to large-scale application of WGM sensors throughout the internet."

Yang's sensor belongs to a category called whispering gallery mode resonators, so named because they work like the famous whispering gallery in St. Paul's Cathedral in London, where someone on the one side of the dome can hear a message spoken to the wall by someone on the other side. Unlike the dome, which has resonances or sweet spots in the audible range, the sensor resonates at light frequencies and also at vibrational or mechanical frequencies, as Yang and her collaborators recently showed.

"In contrast to existing table-sized lab equipment, the mainboard of the WGM sensor is a mere 127 millimeters by 67 millimeters—roughly 5 inches by 2.5 inches—and integrates the entire architecture of the sensor system," said Xiangyi Xu, the paper's first author and a graduate student in Yang's lab. "The sensor itself is made of glass and is the size of just one human hair; it is connected to the mainboard by a single optical fiber. A laser light is used to probe a WGM sensor. Light coupled out of the sensor is sent to a photodetector with a transmission amplifier. A processor controls peripherals such as the laser current drive, monitoring circuit, thermo-electric cooler and Wi-Fi unit," Xu said.

In her WGM, light propagates along the circular rim of a structure by constant internal reflection. Inside the circular rim, light rotates 1 million times. Over that space, light waves detect environmental changes, such as temperature and humidity, for example. The sensor node is monitored by a customized operating systems app that controls the remote system and collects and analyzes sensing signals.

Wireless sensors, whether electronic or photonic (light-based), can monitor such environmental factors as humidity, temperature and air pressure. Applications for wireless sensors encompass environmental and health-care monitoring, precision agricultural practices and smart cities' data-gathering, among other possibilities. Smart cities are connected cities driven by internet data-harvesting. Precision agriculture uses digitized geographic information systems for precision agricultural practices such as soil mapping, which enables precise fertilizer and chemical applications and choice of seed selection for more efficient and profitable farming.

Yang and her colleagues had to address stability issues, which were handled by the customized operation systems app they developed, and miniaturization of bulky laboratory measurement systems.

"We developed a smartphone app to control the sensing system over WiFi," Yang said. "By connecting the sensor system to the internet, we can realize real-time remote control of the system."

In June 2017, Yang and her group mounted the whole system on the outside wall of a building and accumulated a plot of the frequency shift of the resonance. They compared their data with the commercial thermometer.

"Thanks to their small size, the capability and flexibility of wireless photonic sensors can be improved by making them mobile," Yang said.

The researchers also mounted their system on an unmanned drone in May 2017 alongside the commercial thermometer. When the drone flew from one measurement location to others, the resonance frequency of the WGM shifted in response to temperature variations.

"The measurements matched well with results from the commercial thermometer," she said. "The successful demonstrations show the potential applications of our wireless WGM sensor in the IoT. There are numerous promising sensing applications possible with WGM technology, including magnetic, acoustic, environmental and medical sensing."

The miniaturization of resonator sensing systems represents an exciting opportunity for IoT, as it will enable IoT to exploit a new class of photonic sensors with unprecedented sensitivity and capabilities," said Chenyang Lu, the Fullgraf Professor in the Department of Computer Science & Engineering and a co-author of the paper.

More information: Xiangyi Xu et al, Wireless whispering-gallery-mode sensor for thermal sensing and aerial mapping, *Light: Science & Applications* (2018). DOI: 10.1038/s41377-018-0063-4

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