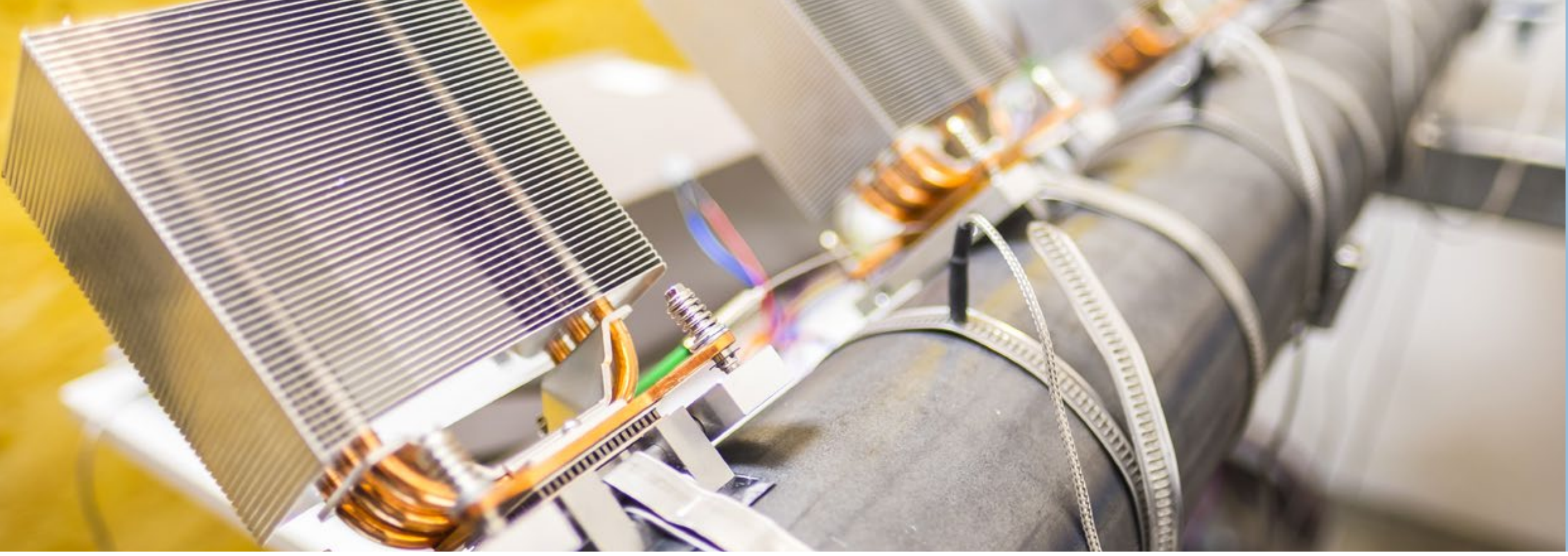


< Self-powered solutions are in demand to meet the energy requirements of the many billions of sensors that make up the Internet of Things. Thermoelectric generators offer up a promising option.

GROUP **THERMOELECTRIC SYSTEMS**

Thermoelectric generators: Mini power plants for the IoT

Thermoelectric generators provide electrical energy from minuscule temperature differences. This makes them perfect for establishing a decentralized supply of small quantities of electrical power – enough to wirelessly operate sensors and transfer data in the Internet of Things (IoT). Fraunhofer IPM is developing both individual thermoelectric components and complete platforms for use in sensor networks.

The world is becoming more interconnected than ever. This is true of people, of course, communicating with other people over the internet – but also, increasingly, of objects. The IoT has been evolving rapidly over the last few years. Billions of devices and systems are already connected, with more being added every day. The IoT communicates not with words, but with sensor data. Sensors are being installed in more and more places. This makes it possible to continuously monitor and control devices, systems, processes and infrastructure. There are already countless practical applications, from smart homes to smart lighting to smart roads. Interconnected production has become a major trend in the industrial sector, too. While some applications focus on saving energy, research and development is turning its attention to the energy consumption of these ever higher-performing interconnected sensors, generating demand for new concepts for energy-efficient, self-powered sensors and data management strategies. And the current trend is toward decentralization, with the aims being local energy provision and decentralized data evaluation.

First mover: Aircraft

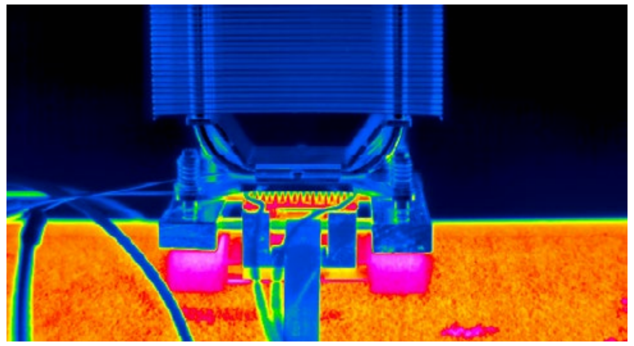
One way to create an energy supply for self-powered sensors is by using thermoelectric generators (TEGs). These obtain small quantities of electricity from temperature differences or changes in temperature over time. The electricity can then be used to supply sensors without the need for batteries or maintenance. This process, described as energy harvesting, promises to be particularly useful in aviation. Wireless operation is advantageous for aircrafts, because cables increase fuel demand – due to their added weight – and system complexity. Fraunhofer IPM has carried out a number of projects over the last decade focused on developing self-powered sensors for the aviation sector, where they are most commonly used for structural health monitoring and predictive maintenance. The sensors can be installed on the airplane's fuselage, for example, to monitor mechanical loads during operation, in turn enabling early detection of any material wear and tear. In a project which ran until the end of 2017, Fraunhofer IPM refined this technology for use with carbon fiber reinforced plastics (CFRPs) and developed an accompanying test environment for simulating flight temperature profiles. The thermoelectric mini power plants draw their energy either from the temperature difference between the airplane's interior and exterior fuselage, or from the temperature change on takeoff and landing. At stationary temperature differences of approximately 40 K, the TEG generates electrical power amounting to about 1 milliwatt per 10 grams.

THERMOELECTRIC GENERATORS (TEG) convert heat flow into electrical power. This works thanks to the Seebeck effect – a phenomenon in which an electrical field is created when two metallic conductors which each have a different temperature are joined. The resulting temperature gradients can be used to "harvest" electricity. Self-powered sensors only require temperature differences of 5–10 Kelvin to generate electrical power in the milliwatt range.

The concept of using changes in temperature over time, like those that regularly occur during airplane takeoff and landing, can also easily be transferred to other applications. Bridges and buildings have high thermal mass, meaning they react very slowly to changes in temperature. When temperatures fluctuate over the course of the day, these fluctuations can be used to form a local temperature gradient, which allows to operate thermoelectric sensors. Utilizing high thermal masses is not the only way to harvest energy from temperature fluctuations over time; reversible chemical processes or the phase transitions of phase-change materials (PCMs) can also be harnessed to this effect.

Edge computing – interpreting data at the point of measurement

As the IoT evolves, the focus is no longer just on ways to power sensors. Current work is increasingly exploring strategies for interpreting and transferring sensor data. If such vast numbers of sensors are to be digitally interconnected, it must be possible to reduce and pre-evaluate the data in a decentralized manner – i.e., at each individual point of measurement. This is the only way to limit the quantity of data so that it can be easily transferred via radio. Fraunhofer IPM is currently working with partners to develop a self-powered measurement platform. In addition to sensor technology and a TEG-based energy supply, the platform includes power management and radio sensor technology. It can be installed on the outer wall of a warm pipe, for example, to generate electrical energy from the temperature difference between the pipe wall and the surrounding medium. A range of parameters can be measured, including temperature, humidity or rate of flow. The measurement data are processed in situ before being transferred to a cloud service via long-range radio. The ultimate goal is to increase the energy yield from TEGs so that measurement data can be continuously collected and processed entirely at the sensor. Analytical strategies based on artificial intelligence (AI) can then be used to ensure that such systems only transfer measurement data onwards once a predefined threshold value is reached.



Self-powered pipe monitoring – the TEG installed on the warm outer wall of this pipe delivers electrical power for operating sensors, power management systems and radio sensor technology.

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