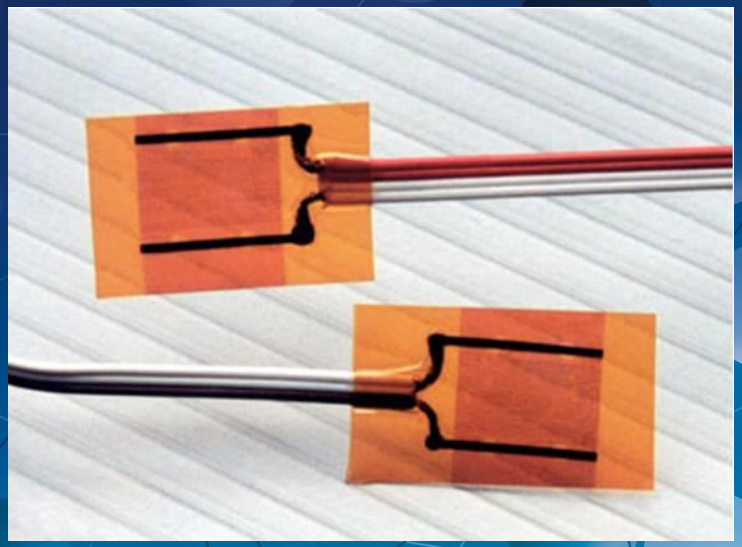
Sensor Technology (TechVision)



Temperature Sensing

Wearable Sensing Devices Poised to Impact Temperature Sensing

D727-TV

January 15, 2016

FROST & SULLIVAN

Contents

Sensor Technology Innovations in Temperature Sensing

Wireless Temperature Sensors

Eindhoven University of Technology (TU/e), Eindhoven, The Netherlands

Miniature Temperature Sensor Harvests Radio Waves

•TU/e researchers have developed a temperature sensor measuring only 2 square millimeters and weighing just 1.6 milligrams.
•It is powered by radio waves that emanate from a base station that transmits10 milliwatts of power.

Competing Aspects
Consumes extremely low power; does not require wires or a battery . A special router with an antenna sends radio waves to the sensor. The router deduces temperature from the frequency of the sensor's signal.

Technology Readiness Level

1 2 3 4 5 6 7 8 9

The sensor is at the technology demonstration stage. To be ready for the industrialization phase, it would require fine tuning for particular applications in terms of lifetime, product optimization, size, and cost.

The wireless sensor powered by radio waves can enable wide use of sensors in smart buildings.
•Such sensors could be efficiently used in smart buildings as they would not need replacement of batteries.

Market Readiness and Commercialization Strategy
A key application envisioned for the small, inexpensive sensor is smart buildings. Moreover, the small, inexpensive sensor is generating interest in numerous applications beyond those envisioned by the researchers.

"" It is really exiting to see opportunities for the technology in so many applications," Peter Baltus, TU/E professor of wireless technology "

Impact & Opportunities

Commercialization / Wide Scale Adoption Year

The wireless sensor is envisioned to have opportunities for significant adoption during the next 3-5 years. Wider adoption will be enabled by increasing the sensor's range (which is currently 2.5 centimeters) to 1 meter and eventually 5 meters. Under a best case scenario, the sensor could be ready for commercialization within 1 to 1 and ½ years.

Impact on Industries / Specific Apps

The sensor, which can work beneath a layer of paint, plaster, or concrete, is anticipated to have particular opportunities in smart buildings. The technology also allows for wireless sensors to detect parameters such as movement, light, or humidity.

Market Potential/Opportunity

The sensor, which is based on 65 nm CMOS technology, has potential in varied applications, including payment systems, wireless identification, and industrial production systems.

Technology Convergence

The technology dovetails with and leverages technologies or megatrends such as wireless sensing, energy harvesting, and smart cities.

Fiber Optic-based Temperature Sensor

University of Nebraska-Lincoln–Sensing platform for measuring ocean dynamics

Tech Profile

The fiber optic temperature sensor uses a silicon Fabry-Perot cavity and a silicon pillar attached to the tip of the fiber. The silicon helps to register the smallest changes in temperature at a fast rate.

Innovation Attributes

- *Registers temperature changes at smaller scales*
- *High-speed sensor with faster response rate*

University of Nebraska Lincoln

Competing Aspects

- *Easy to fabricate*
- *The fiber optic temperature sensor can register changes in temperature 30 times faster than the sensors available in the market*

Market Entry Strategies

The university has developed this technology in collaboration with the US Naval Research Laboratory. Going further, the collaboration can lead to sensors for defense applications (e.g., underwater transmission of optical or acoustic signals) and climate forecasting.

Impact & Opportunities

Wide-scale Adoption

Quantification of the heat flow at very high rates and on a small scale, is important for predicting circulation of ocean currents and changes in climate. The technology has potential to be employed widely by the US Navy and climate research and forecasting organizations.

Market Opportunity

The technology has opportunities in oceanography (such as predicting ocean currents, underwater communication of optical or acoustic signals) and in climate prediction.

Technology Convergence

The hardware of the technology will converge with the novel signal processing method. This method will help reduce the disturbances caused by temperature fluctuations and signal noise by averaging the wavelength peak.

Technology Readiness Level

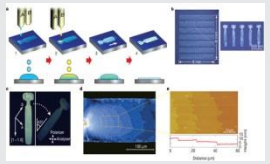
1 2 3 4 5 6 7 8 9

Self-Powered Wearable Armband to Measure Temperature

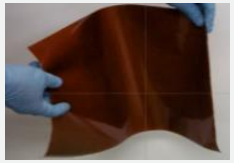
University of Tokyo–Flexible, self-powered smart wearable fever armband for healthcare

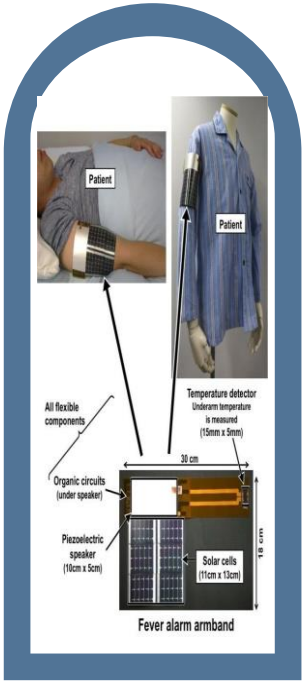
Wearable armband carrying temperature sensors can be deployed in healthcare

Inkjet Printing



Polymer Substrate





- **Flexible Amorphous Silicon Solar Panel**
- **Piezoelectric Speaker**
- **Temperature Sensor**
- **Flexible Organic Power Supply Circuit**

2013 2014 2015 2016 2017 2018 2019 2020

The wearable armband can be expected to be the gateway to the connected world. Wearable devices offer a wide range of functionality in an unobtrusive way to users. The wearable fever armband has the ability to extend the user's senses and provide useful information anytime and anywhere. Characteristics of wearable devices, such as lightweight, water resistance, flexibility, and durability, enhance the user's experience.

Industry Initiatives

There is increased adoption of smart devices currently. A similar trend can be expected in the adoption of wearable armbands. Development of connected and smart living can bolster the growth of wearable fever arm bands.

Working Principle

- An armband network will be integrated in large-scale structures with thin wires. The armband can be stretched and can be used directly on the skin or placed on top of cloth. Inkjet printing fabrication processes will be employed to fabricate a circuit on a silicon wafer.
- The circuit of the armband is preset to certain values; and once the temperature is increased from the preset values, the circuit triggers an alarm, called fever alarm by the researchers.

Stretchable Hydrogel Band-Aid for Temperature Sensing

Massachusetts Institute of Technology–Developing hydrogel Band-Aid for drug delivery and temperature sensing

Tech. Profile

The stretchable hydrogel Band-Aid can be used in any part of the body and can also be used as an implantable device. The Band-Aid is developed with the help of conducting wires, a semiconductor chip, light emitting diode (LED) lights and temperature sensors. To develop a robust hydrogel, the researchers have mixed water with the biopolymers with a stiffness of 10 to 100 kilopascals.

Wide-scale Adoption

Trends toward personalized medicine and wearable electronics are significant factors driving the adoption of the wearable Band-Aid. The hydrogel technology has potential to be disruptive in such areas as “smart wound dressing” and drug delivery and in implantable glucose sensors.

Market Opportunity

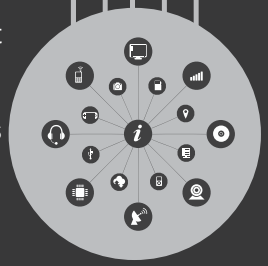
The Band-Aid with multi-functional capabilities has opportunities to be widely adopted and increase the global revenue of the healthcare wearable market. It is expected to be tagged at a premium price. The price can be expected to reduced after wider adoption and with the introduction of new technologies.

Competing Aspects

- ✓ Stretchable
- ✓ Real-time drug delivery
- ✓ Biocompatible
- ✓ Highly deformable

Innovation Attributes

The Band-Aid is designed to be installed on the skin or inside the body. To detect temperature changes in the human body, the temperature sensor will remain in place to monitor parameters, such as fever and deliver drugs in real time.



Market Entry Strategies

One possible route would be to license the technology to hospitals and wearable device manufacturers. Wearable device manufacturers are further expected to capture market share by selling products with the Band–Aid technology for added value.

Technology Convergence

In the future, wearable electronics products and devices are expected to have better connectivity. In addition, the Band-Aid technology will reinforce contextual awareness and pervasive computing.

Technology Readiness Level 1 2 3 4 5 6 7 8 9

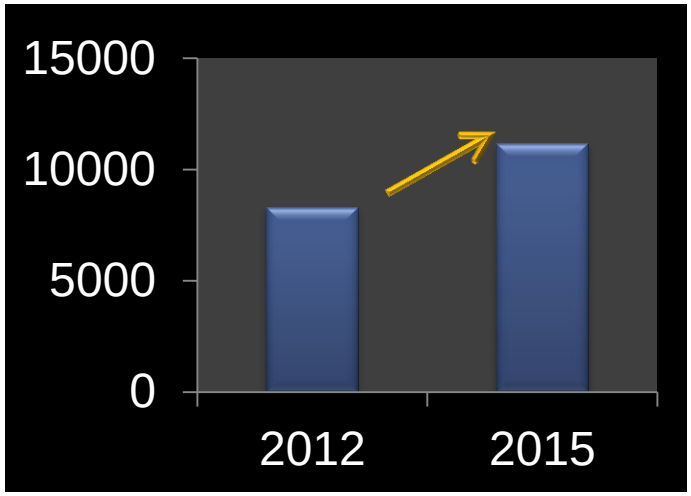
Strategic Insights

Strategic Insights

Technology Roadmap

2016	2017	2018	2019	2020
Research is still needed to identify effective energy harvesting techniques that make wireless sensors reliable and long lasting to meet service needs.	Strategic alliances or partnerships with OEMs	Wearing your own device for real-time monitoring	Implantable devices	Smart Drug Delivery

Intellectual Property (IP)



- According to the patent filing trends, researchers are moving toward on-demand temperature measuring devices, with certain advantages such as reliability, low cost, and durability. Moreover, they can be easily integrated into the existing structure.
- In the healthcare domain, wearable temperature sensor patent activities are gaining significant traction. In the coming years, wearable temperature sensors are expected to witness significant patent filing activity. The highest concentration of patent activity can be seen in Japan, followed by the USA, China, Korea, and Europe.
- Some of the participants investing in R&D of temperature sensors include Scientific Instruments, AdSem Inc., LakeShore Cryotronics, Cryogenic Control Systems Inc., and Neocera Inc.

Strategic Insights: Drivers and Restraints for Temperature Sensors

Drivers

- ✓ High accuracy
- ✓ Return on investment
- ✓ Increase in HVAC applications will boost revenue
- ✓ Advancements in wireless sensing and energy harvesting technologies
- ✓ Advancements in smart materials
- ✓ Technology advancements in materials and integrated sensors

Restraints

- Ẋ Increased user-controlled monitoring needs sustain development
- Ẋ Increased emphasis on service supports market penetration
- Ẋ High level of competition and price discounts restrict survival

Funding

- Funding support by government and venture capitalists is expected to accelerate the commercialization of prototypes. Technology developers would be able to bring innovative ideas to the market with financial support.
- The government and defense sectors in different countries are heavily funding R&D activities in temperature sensing.

R&D Focus Areas

- High-temperature sensor materials such as platinum, tungsten, tantalum, and alumina
- Extreme high-temperature sensing materials such as beryllium oxide, magnesium oxide, thorium oxide, and yttrium oxide
- Incorporating of temperature sensors in stretchable, soft materials
- Harvesting energy from body temperature
- High-temperature thermocouples

The 2020 Scenario

- ❑ Mobile devices, combined with wireless sensors and advanced communication technologies, will set the foundation for the wearable temperature sensing market. For the last few years, there has been tremendous growth in the wearable electronics market, particularly in the health and fitness sector.
- ❑ For wearable temperature sensing devices to be successful, wearable vendors will have to forge alliances and partnerships with cross-industry stakeholders. Such synergistic convergence will unlock doors to new application areas.

Key Patents and Industry Interactions

Key Patents—World

No.	Patent No.	Publication Date	Title	Assignee
1	**WO/2016/001956**	07.01.2016	HOT WATER STORAGE TANK UNIT, HOT WATER STORAGE-TYPE WATER HEATER, AND METHOD FOR INSTALLING ALTERNATIVE TEMPERATURE SENSOR IN HOT WATER STORAGE UNIT	HITACHI APPLIANCES, Inc.
	In hot water storage units of conventional hot water storage-type water heaters, a takeout portion is formed in a heat insulating material, and a defective temperature sensor can be replaced from the takeout portion. However, if the takeout portion is provided, a heat leak occurs therefrom, and therefore the provision of the takeout portion is undesirable in terms of heat insulation. The purpose of the present invention is to provide a hot water storage-type water heater which achieves both a heat insulating property and maintainability. To achieve this purpose, this hot water storage unit comprises a hot water storage tank that stores hot water, a temperature sensor provided outside the hot water storage tank, a case that surrounds the hot water storage tank, and a foam heat insulating material filled between the hot water storage tank and the case, and bonding force between the hot water storage tank and the foam heat insulating material in the vicinity of the temperature sensor is made weaker than bonding force between the hot water storage tank and the foam heat insulating material outside the vicinity of the temperature sensor.			
2	**WO/2016/001663**	07.01.2016	CATALYTIC REACTORS COMPRISING DISTRIBUTED TEMPERATURE SENSORS	COMPACT GTL PLC
	A catalytic reactor is provided comprising a plurality of first flow channels including a catalyst for a first reaction; a plurality of second flow channels arranged alternately with the first flow channels; adjacent first and second flow channels being separated by a divider plate (13a, 13b), and a distributed temperature sensor such as an optical fibre cable (19). The distributed temperature sensor may be located within the divider plate, or within one or 10 more of the flow channels.			

Key Patents—USA

No.	Patent No.	Publication Date	Title	Assignee
3	**US20150377698**	31.12.2015	SENSOR ARRANGEMENT FOR LIGHT SENSING AND TEMPERATURE SENSING AND METHOD FOR LIGHT SENSING AND TEMPERATURE SENSING	ams AG
	A sensor arrangement for light sensing and temperature sensing comprises a first sensor input (**1**) for connecting a temperature sensor (**11**) and a second sensor input (**2**) for connecting a light sensor (**21**), in particular an ambient light sensor. A sensor switch (S**3**) electrically connects either the first or the second sensor input (**1, 2**) to an integration input (**41**) of an integrating analog-to-digital converter (**4**). A reference circuit (**5**) connects to the integration input (**41**) via a first switch (S**2**). A first reference input (**42**) of the integrating analog-to-digital converter (**4**) is to be connected with a first reference potential (Vb**1**). A counter (**6**) connects to an integration output (**43**) of the integrating analog-to-digital converter (**4**). And a controller unit (**6**) connects to the counter (**6**) and is designed to control the first switch (S**2**) depending on an integrated sensor signal (Vout) integrated by the integrating analog-to-digital converter (**4**).			
4	**US20150377717**	31.12.2015	ELECTRONIC TEMPERATURE SENSOR FOR MEASURING THE JUNCTION TEMPERATURE OF AN ELECTRONIC POWER SWITCH DURING OPERATION, AND METHOD FOR MEASURING THE TEMPERATURE OF THE JUNCTION BY THIS ELECTRONIC SENSOR	TECHNOFAN
	An electronic temperature sensor for measuring the junction temperature of an electronic power switch (**4**) of a static converter (**8**) includes an injection source of a calibrated measurement current (**20**) and a differential voltage measurement amplifier (**76; 276**). The electronic temperature sensor includes a first series connection (**26**) element and a second series connection (**28**) connected respectively to the inlet terminals (**78, 80**) of the differential voltage amplifier (**76; 276**). The first and second series connection elements (**26, 28; 224, 226**) are configured to protect the amplifier against a high voltage, have essentially identical electrical characteristics and are included in the set formed by resistances and high-voltage (HV) rapid diodes.			

Industry Interactions

Xuanhe Zhao

Associate Professor, Department of Mechanical Engineering, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA, 02139-4307
Phone: 617-324-6367
E-mail: zhaox@MIT.EDU

Ming Han

Associate Professor, University of Nebraska-Lincoln, 1400 R Street, Lincoln, NE 68588.
Phone: 402-472-9618.
E-mail: mhan3@unl.edu

Peter Baltus

Director Centre for Wireless Technology, Eindhoven, Technische Universiteit Eindhoven, P.O. Box 513, 5600 MB Eindhoven.
Phone: +31-40-247-3393
E-mail: p.g.m.baltus@tue.nl

Takayasu Sakurai

Professor, Institute of Industrial Science, The University of Tokyo, Komaba 4-6-1, Meguro-ku, Tokyo 153-8505, Japan.
Phone: +81-3-5452-6251/625.
E-mail: tsakurai@iis.u-tokyo.ac.jp.