Sensors Applications
Volume 5

Sensors in Household Appliances

Edited by
G. R. Tschulena, A. Lahrmann

Series Editors:
J. Hesse, J. W. Gardner, W. Göpel (†)

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Series Editors

Prof. Dr. J. Hesse
formerly of Carl Zeiss, Jena
Bismarckallee 32 c
14193 Berlin
Germany

Prof. J. W. Gardner
University of Warwick
Division of Electrical & Electronic Engineering
Coventry CV4 7AL
United Kingdom

Prof. Dr. W. Göpel †
Institut für Physikalische
und Theoretische Chemie
Universität Tübingen
Auf der Morgenstelle 8
72076 Tübingen
Germany

Volume Editors

Dr. G. R. Tschulena
sgt Sensorberatung
Reichenberger Straße 5
61273 Wehrheim
Germany

Prof. Dr. A. Lahrmann
Fachhochschule für Technik und Wirtschaft
Ingenieurwissenschaften II
Produktentwicklung
Blankenburger Pflasterweg 102
13129 Berlin
Germany

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Preface to the Series

As the use of microelectronics became increasingly indispensable in measurement and control technology, so there was an increasing need for suitable sensors. From the mid-Seventies onwards sensors technology developed by leaps and bounds and within ten years had reached the point where it seemed desirable to publish a survey of what had been achieved so far. At the request of publishers WILEY-VCH, the task of editing was taken on by Wolfgang Göpel of the University of Tübingen (Germany), Joachim Hesse of Carl Zeiss (Germany) and Jay Zemel of the University of Philadelphia (USA), and between 1989 and 1995 a series called *Sensors* was published in 8 volumes covering the field to date. The material was grouped and presented according to the underlying physical principles and reflected the degree of maturity of the respective methods and products. It was written primarily with researchers and design engineers in mind, and new developments have been published each year in one or two supplementary volumes called *Sensors Update*.

Both the publishers and the series editors, however, were agreed from the start that eventually sensor users would want to see publications only dealing with their own specific technical or scientific fields. Sure enough, during the Nineties we saw significant developments in applications for sensor technology, and it is now an indispensable part of many industrial processes and systems. It is timely, therefore, to launch a new series, *Sensors Applications*. WILEY-VCH again commissioned Wolfgang Göpel and Joachim Hesse to plan the series, but sadly Wolfgang Göpel suffered a fatal accident in June 1999 and did not live to see publication. We are fortunate that Julian Gardner of the University of Warwick has been able to take his place, but Wolfgang Göpel remains a co-editor posthumously and will not be forgotten.

The series of *Sensors Applications* will deal with the use of sensors in the key technical and economic sectors and systems: *Sensors in Manufacturing, Intelligent Buildings, Medicine and Health Care, Automotive Technology, Aerospace Technology, Environmental Technology* and *Household Appliances*. Each volume will be edited by specialists in the field. Individual volumes may differ in certain respects as dictated by the topic, but the emphasis in each case will be on the process or system in question: which sensor is used, where, how and why, and exactly what the benefits are to the user. The process or system itself will of course be outlined and

the volume will close with a look ahead to likely developments and applications in the future. Actual sensor functions will only be described where it seems necessary for an understanding of how they relate to the process or system. The basic principles can always be found in the earlier series of *Sensors* and *Sensors Update*.

The series editors would like to express their warm appreciation in the colleagues who have contributed their expertise as volume editors or authors. We are deeply indebted to the publisher and would like to thank in particular Dr. Peter Gregory, Dr. Jörn Ritterbusch and Dr. Claudia Barzen for their constructive assistance both with the editorial detail and the publishing venture in general. We trust that our endeavors will meet with the reader's approval.

Oberkochen and Coventry, November 2000

Joachim Hesse
Julian W. Gardner

Foreword

NEXUS is a network of experts aimed to introduce more microsystems in the industrial applications. NEXUS operates within industrial and academic organisations, primarily in Europe, but also has significant high-level membership from other continents, including USA and Far East Asia.

In its starting period, about one decade ago, NEXUS was mainly driven by academic members, working on dissemination of information on technical developments and market possibilities. Industrial interest soon expanded the network and the current membership now exceeds 1000. Since mid-2001 the NEXUS network has been transformed into the "NEXUS Association" based in Grenoble, France. NEXUS activities continue to be strongly supported by the European Commission and MEMS/MST-related industry.

In response to the needs of the membership and the interest of the European Commission the following specific activities were carried out:

- The "NEXUS Market Analysis for Microsystems" was initiated in 1998 and the first edition published in 2000. This second edition was published in Spring 2002, covering the period to the year 2005.
- The "NEXUS Technological Roadmap for Microsystems" was published in Dec. 2000, with and updated and broadened report due in 2002/2003.
- The members are also informed regularly on new European and national research an development support activities in the areas of microsystem technology and nanotechnology.

The NEXUS User Supplier Clubs provide the means for members to collect, discuss and to verify technical and market-related information. These USC operate in the application areas of:

- Automotive
- Pharmaceutical and diagnostics
- Medical Devices
- Industrial Process Control
- Peripherals and multimedia
- Aerospace and geophysics
- Telecommunication

- Household appliances
- CAD tools
- Packaging
- Nano materials technology

The "NEXUS User-Supplier-Club Household Appliances" was founded during the first European conference on "Commercialisation of Microsystems" held in Dortmund in 1999. This Club has grown rapidly to a current membership of more than 40 from major and smaller appliance companies, sensor and MST supplier companies and from academic institutions all over Western Europe.

The Club holds 3 to 4 meetings per year, and with an exchange of information and documents by e-Mail. Specifically the USC Household Appliances meetings take place at factories of member companies, of research organisations, or in conjunction with large fairs.

The household industry in Europe employs significant numbers of people and requires high volumes, but it operates in a highly competitive area. The use of more and better adapted electronics has been a major driving force in the last decade and provides one means to reach the overall objective of reducing energy, water and detergent consumption. This coupled to the introduction of more reliable and cost effective sensors and microsystems provides a means of remaining competitive in a global economy.

The work on this book was one of the successful outcomes from the activities of the NEXUS User Supplier Club on Household Appliances. We wish the members well and hope for a successful continuation of these activities in the future.

Gaetan Menozzi
Chairman of NEXUS

Contents

List of Contributors

Kjumar Abkai
Friatec AG
Steinzeugstr. 50
68229 Mannheim
Germany

Willi Buchmeier
Henkel KGaA
Henkelstr. 67
40191 Düsseldorf
Germany

Sebastian Bütefisch
First Sensor Technology GmbH
Carl-Scheele-Str. 16
12489 Berlin
Germany

Michael Dreja
Henkel KGaA
Henkelstr. 67
40191 Düsseldorf
Germany

Heinz-Werner Etzkorn
Gaswärme-Institut e.V. Essen
Hafenstraße 101
45356 Essen
Germany

Joachim Goschnick
Forschungszentrum Karlsruhe GmbH
IFIA Inst. für Instrumentelle Analytik
Postfach 3640
76021 Karlsruhe
Germany

Rudolf Herden
Miele & Cie. GmbH & Co.
Carl-Miele-Straße 29
33332 Gütersloh
Germany

Oliver Hilt
twlux Halbleitertechnologien
Berlin AG
Ostendstr. 25
12459 Berlin
Germany

Ulrich Hoefer
Steinel Solutions AG
Allmeindstr. 10
8840 Einsiedeln
Switzerland

Eduard Huber
Vertrieb/Projekte OEM Sensoren
Micro-Epsilon Messtechnik
GmbH & Co. KG
Königbacher Straße 15
94496 Ortenburg
Germany

Holger Janssen
Gaswärme-Institut e.V. Essen
Hafenstraße 101
45356 Essen
Germany

Ulrich Koch
Managing Director
eBuilding GmbH
Weinheimer Str. 68
68309 Mannheim
Germany

Reiner Körber
Forschungszentrum Karlsruhe GmbH
IFIA Inst. für Instrumentelle Analytik
Postfach 3640
76021 Karlsruhe
Germany

Bernhard Kraus
Braun GmbH
Frankfurter Str. 145
61476 Kronberg/Taunus
Germany

Claudia Kühner
Kachikoshi PR
Annweiler Straße 30
76829 Landau
Germany

Andreas Lahrmann
Fachhochschule für Technik
und Wirtschaft
Ingenieurwissenschaften II
Produktentwicklung
Blankenburger Pflasterweg 102
13129 Berlin
Germany

Tjerk bij de Leij
Philips Domestic Appliances
and Personal Care B.V.
Postbus 20100
9200 CA Drachten
The Netherlands

Martin Meggle
Steinel Vertrieb GmbH
Dieselstraße 80–84
33442 Herzebrock-Clarholz
Germany

Ulrich Meier
Meder electronic AG
Friedrich-List-Strasse 6
78234 Engen-Welschingen
Germany

Matthias Muziol
Heraeus Sensor-Nite GmbH
Reinhard Heraeus Ring 23
63801 Kleinostheim
Germany

Stefan Rusche
Gaswärme-Institut e.V. Essen
Hafenstraße 101
45356 Essen
Germany

Wolfgang von Rybinski
Henkel KGaA
Henkelstr. 67
40191 Düsseldorf
Germany

Peter Schmiedel
Henkel KGaA
Henkelstr. 67
40191 Düsseldorf
Germany

Florian Solzbacher
First Sensor Technology GmbH
Carl-Scheele-Str. 16
12489 Berlin
Germany

Rainer Stamminger
Electrolux
AEG Hausgeräte GmbH
Muggenhoferstr. 135
90429 Nürnberg
Germany

Harald Steinmueller
Electrolux Home Products PTY, Ltd.
19, Pope St.
Beverly SA 5009
Australia

Guido Tschulena
Sgt Sensor Consulting
Dr. Guido Tschulena
Reichenberger Str. 5
61273 Wehrheim
Germany

Tilman Weiss
twlux Halbleitertechnologien
Berlin AG
Ostendstr. 25
12459 Berlin
Germany

Tilo Weiss
Henkel KGaA
Henkelstr. 67
40191 Düsseldorf
Germany

Günter Wentzlaff
Facility Management
Hochschule Niederrhein
Reinarzstraße 49
47805 Krefeld
Germany

1
The Increasing Importance of Sensors in Household Appliances

A. Lahrmann and G. Tschulena

1.1
Introduction

Household appliances make up one of the largest markets for electrotechnical and electronic products. While comparatively simple versions of sensors and microsystem products, such as temperature sensors or level sensors, have long been used in household appliances, new and improved sensors conquer the market at a breathtaking rate. The way modern sensors with intelligent control systems are used is one of the main distinguishing features between the various products and companies.

The household appliance industry produces

- large household appliances, which make up about three quarters of the annual turnover. About 60 Million units are produced in Europe and about 150 million units worldwide.
- small household appliances, (responsible for about 20 to 25% of the turnover, with another about 23 million units produced annually in Western Europe).
- electrical and gas heating and climate conditioning equipment (responsible for about 5 to 6% of the turnover, according to the ZVEI-GfK data for 1998)

These industries comprise the appliances described in more detail in Tabs 1.1 and 1.2.

More details on appliance markets are given in Chapter 2, together with some data on the sensors in question. There has been some recent research into the markets of modern micromechanical sensors in household appliances, documenting the market potential for various types of sensors in this area, including those for pressure, acceleration and tilt, thermopiles, flow and gas sensors [3]. Examples of future developments will also be given.

Some applications shown in Tab. 1.1 are described in Chapter 3 of this book. As home laundry applications are of major importance as the largest sector, Chapter 3.1 is dedicated to the major driving forces and developments in this area.

Combustion control for domestic hot water production is another important area where modern sensor technology comes in. New developments are discussed in Chapter 3.2.

Tab. 1.1 Classification scheme for household appliances.

Large household appliances	Home laundry appliances, with washing machines, dryers, combined washing machines and dryers; Dish washers; Cookers, with gas cookers, electric cookers, ovens, cooker hoods, microwave appliances; Refrigeration appliances, with refrigerators, combined fridge-freezers, upright and chest freezers Home comfort appliances, with water heaters, air conditioning, and cooling units, gas heaters, home automation systems. Also air filters, like in kitchen vapor extractor hood systems, for vacuum cleaners and for air conditioning systems.
Small household appliances	Floor care systems, with vacuum cleaners Irons Coffee machines Mixers Tooth care equipment Shavers Blood pressure equipment Electronic thermometers
Heating and climate control	Heater systems Warm water boilers Climate conditioning equipment
Security and safety	Intruder alarm Security systems Fire detection systems, with sensors for – temperature – toxic gases like CO, CO_2, exhaust gases, smoke, etc. – combustible gases like CH_4, C_2H_6 flame detection, fire detectors, caravans with gas detectors, etc.

In the small appliances sector, the picture is more diffuse. As these appliances usually involve low cost technology, sensors were only introduced fairly recently. However, some interesting developments have taken place here. For instance, thermopiles for remote temperature sensing that were introduced in the late 1990s are now found in hairdryers and in toasters made by Philips DAP (as described in Chapter 3.4). Since their introduction, the use of remote temperature sensors has been increasing, and further applications of the technology can be expected in the next decade. One interesting new appliance is the ear thermometer, e.g. from Braun, which is described in Chapter 3.5.

Applications for multifunctional chemical sensors to detect constituents in liquids as well as gases are going to expand rapidly in the near future. Chemical sensors act as "noses" and can be extremely useful in kitchens, helping in a range of tasks. from exhaust control to monitoring of cooking, frying or baking processes, as described in Chapter 3.3. Further applications of such "micronose sensors" include air conditioning and climate control as well as safety devices e.g. fire alarms or gas detectors for the prevention of health and fire hazards.

Monitoring the use of detergents is a specific household task which should be automatically controlled as far as possible in order to make use of modern microelectronic systems with sensors. Chapter 4 "Sensors for Detergency" gives a good overview of washing agent monitoring sensors.

1.2 Sensors in Household Appliances

More and more sensors and microsystem devices are being used in a wide range of household appliances, and the number is set to increase in the near future. Several technologies are used for such sensors, as described in the subchapters of Chapter 5. An evaluating synopsis of these sensors is given in Tab. 1.2 for large household appliances, for small household appliances in Tab. 1.3 and for heating and climate control in Tab. 1.4.

The sensors are also classified according to the major technologies used in their production. Technologies that allow large-scale production of reliable sensors at low cost are becoming particularly important. The compatibility of such sensors with electronic signal conditioning is an additional bonus.

We also give a rough overview of the product development status of the various sensors. Some are in use and available in large quantities, while others are still being developed. Their introduction may be imminent, depending on the combined interests of the appliance industry and the consumers.

The following sensor features are of special interest for the production of washing machines and dishwashers

- The use of pressure sensors for water level switches, or in a more sophisticated form also for foam content surveillance in washing machines and dryers.
- Introduction of chemical sensors for water quality monitoring. This includes parameters like turbidity, color, surface tension, detergent concentrations, pH-value etc. Optoelectronic systems are used to monitor the turbidity of washing water, which then determines the number of rinsing cycles (aqua-sensor system).
- Magnetic sensors for controlling the movements of the water spray arms in dish washers

Improved sensors will be used in many other household appliances, such as

- contactless monitoring systems, including e. g. micromachined thermopile infrared sensors for temperature control, which can also be used in cookers, hair care appliances and toasters.
- Air mass flow sensors can be used in fans and vacuum cleaners.
- Acceleration or tilt sensors are used in irons.
- Automatic baking control by introduction of intelligent multigas sensors (artificial noses).

Tab. 1.2 Development status of sensors used for large household appliances.

Function	*Device*	*Technology used*	*Status*
Automated baking	Multigas sensor, electronic noses	Non MST, Infrared sensing MST	UD
Colour	Spectrometers	Potential MST	UD
Current sensors	Magnetoresistive Sensors	Thin Film, MST	P
Detergent control: Cleanliness, dirt monitoring	Turbidity Conductivity	Optical	P P
Dirt content			UD
Dosing units for detergents + Rinsing aids	Macro Micro	Non MST MST	
Engine overload	Temperature		P
Foam content	Pressure Sensor	MST?	UD
Flow for liquids and gases	Flow turbines Pressure sensors...	MST? MST	P
Gas quality	Electronic noses, multigas sensors	MST? Optical?	UD
Humidity (hairdriers)	Infrared Capacitive	MST	
Humidity control	Conductivity sensor		UD
Humidity/Moisture status in dryers	Capacitive	MST	UD
Motion (Water spray arm movement)	Magnetic	MST	P
Motors	– Micromotors Ultrasonic motors	No MST products until now MST	– UD
Pressure sensors, switches	Membrane actuated relay Si-pressure sensors	Non-MST MST	P P
Proximity	Capacitive Inductive Magnetic LEDs – Lasers	MST in future?	P
Push button	Capacitive sensors Touch sensitive switches		P
Rotation, speed	Tachogenerators Magnetic	No MST MST	
Security, intruder alarm	Vibration Tilt sensors	MST? MST?	

Explanation: MST Micro System Technology
UD Under Development
P Product on the market

Tab. 1.2 (continued)

Function	*Device*	*Technology used*	*Status*
Security systems for gas heating	Gas sensors	MST?	P
	Temperature sensors	–	P
	UV sensors	Optical	DU
Temperature control	NTC, PTC resistor	No MST	P
	Ni-, Pt-film resistors	Thin film technology,	P
	Expansion capillary thermostats	MST	P
		No MST	P
	Electromechanical thermostats	No MST	P
	Thermocouples	–	P
	Infrared radiation	MST	P
Tilt	Acceleration sensors	MST	P
	Tilt sensors	MST	
Timers			
Torque			
Valves, dosing units	–	No MST until now	P
	Microvalves	MST	UD
Vision	Photodiode-arrays, cameras	Optical	UD
Vibration	Acceleration sensors	MST	
Wash quality	Tagging		UD
Water flow measurement	Turbine flow meters	Magnetic	P
Water level	Pressure switches	MST	P
	Magnetic actuated relays	MST	
Water quality (input water) Wash water	Turbidity	MST?	First products
	PH-sensors		
	Ion-FETs		
Weight sensors	Piezoresistors, strain gauges	MST	
		No MST	
	Pressure sensitive membranes		

Gas sensors are a new type of sensor for which there is an increasing demand. We include a description of state-of-the-art-gas sensors in Chapter 5.3.

Long-term stability (more than 10 years lifetime) under realistic conditions is a crucial feature in all sensors, especially gas sensors.

Several sensors are in use in the heating and climate control sector, such as

- Temperature sensors and switches
- Pressure sensors and switches
- Flow sensors for liquids and for gas.

Tab. 1.3 Development status of devices for small household appliances.

Function	*Device*	*Technology used*	*Status*
Contactless temperature measurement	Infrared sensors	MST	P UD
Automated baking	Multigas sensor, electronic nose		R&D
Humidity (hairdriers)	Infrared Capacitive		
Rotational speed	Tacho generators Magnetic sensors		P UD
Distance sensors	Optical (?)		UD

Many of them are covered in the previous tables 1.2 and 1.3; some additional specific sensors are listed in Tab. 1.4.

Temperature control is one of the longest established and most important functions in household appliances. One example of modern thin film fabrication technology of platinum temperature sensors with application examples in the kitchen in hot plates and ovens is given in Chapter 5.1.

Reed relais are an example of well-established distance sensing technology. They are used in millions of appliance units and are described in Chapter 5.2.

Reed technology applications include
- measuring the flow of liquids in turbine-like meters,
- the water level determination, e.g. in coffee machines, or in monitoring the water level of softeners and clarifier in dishwashers
- controlling the movements of dishwasher spray-arms
- detecting the drum position in washing machines
- security control for appliance door detection
- electric toothbrush
- reed sensors in carpet cleaners
- detecting of movements or end positions in massage chairs, special lifts for bathtubs, hospital beds,

A survey on several gas sensing methods is given in Chapter 5.3. There is a great need for several types of gas sensors in order to detect the wide range of harmful gases in the human environment – toxic and/or explosive gases like carbon monoxide and natural gas. An uncomfortable room climate is probably a contributing factor to the so-called "sick building" syndrome. Furthermore, there are about 10 000 additional air components which can affect our health. Therefore many gas sensor working methods are in use, comprising
- semiconductor oxide gas sensors, based e.g. on tin oxide or gallium oxide,
- pellistors for the detection of flammable gases,

Tab. 1.4 Development status of devices for heating and climate control.

Function	*Device*	*Technology used*	*Status*
Temperature sensors and switches	NTC, PTC resistors Bimetals Film sensors	No MST No MST MST	
Contactless temperature measurement	Infrared sensors	MST	P UD
Pressure sensors and switches		MST	
Flow sensors for liquids and for gas.		MST?	
Valves, dosing systems		No MST today MST?	
Exhaust control systems	Lambda sensors		
Security systems	Gas sensors Temperature sensors UV sensors		
Gas quality	Multigas sensor, electronic nose		R&D

- amperometric or potentiometric liquid state electrochemical gas sensors,
- potentiometric and amperometric solid state electrochemical gas sensors,
- optical gas sensors.

Some application areas of gas sensors are described in chapter 5.3, including gas and fuel powered domestic burner control, air quality sensing, indoor detection of CO, and natural gas detection. Several further applications of gas sensors are still in the development stage, e.g. for cooking and frying control, or for controlling the self-cleaning procedure (pyrolysis) of ovens.

In Chapter 5.4, optical ultraviolet radiation sensors are described, including UV-enhanced silicon-based pn diodes, detectors made from other wide band gap materials in crystalline or polycrystalline form, the latter being a new, less costly alternative. Other domestic applications are personal UV exposure dosimetry, surveillance of sun beds, flame scanning in gas and oil burners, fire alarm monitors and water sterilization equipment surveillance.

Displacement sensors developed for application in the dampers of washing machines are described in Chapter 5.5. Measuring the displacement of washing machine drums allows direct control of any unbalance in the washing machine. Thus, vibrations will be reduced and the lifespan of the washing machine prolonged. Furthermore, the electrical power needed for the drives can be reduced, and the washing process can be adjusted to the load by automatic selection of an appropriate washing program.

It is also interesting to look into the future use of sensors in household appliances. An attempt to do this is made in Chapter 6 where the influence factors in this broad field are analyzed. These include socio-economic data of the end users (like age of the population) and their preferences (like savings of energy, water and detergents), ease of use and cost of ownership, as described in Chapter 6.1.
One specific and interesting future development can be foreseen – the integration of home appliances into heretofore strictly separated areas, such as

- telecommunication and internet services
- home entertainment
- computing
- heating and ventilation, and even
- building controls

For a successful integration, the domestic appliances and all the other functions must be able to communicate with each other, which requires compatible software as well as hardware. Such digitalization may occur not only at appliance level, but also at the sensor level, as described in Chapter 6.2.

An example of such an integrated home project still under construction is given in Chapter 6.3, which describes how in South West Germany about 1200 households will be interconnected in a cost-friendly way to share comfort, service and security-related functions.

1.3 References

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