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Simple and Low-Cost Wireless Distributed Measurement System

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Abstract: This paper describes the design and realization of a simple and low-cost system for distributed measurements. Traditional handheld digital multimeters have been equipped with a radio-frequency interface in order to implement what the authors call WDMM, the basic block of a wireless multi-probe data logger. New functionalities require very few components and result in a cost increase of less than 10$. In addition, also maintenance has been facilitated since tracking data such as working state or last calibration time are available to the user.

Data inquiry can be performed by a purposely designed module that has the same hardware of the WDMM but a different user interface or by a PDA (Personal Digital Assistant) or a traditional personal computer thanks to a USB connection. Simple supervisory software has been realized under the LabVIEW graphical programming environment. *Copyright © 2007 IFSA.*

Keywords: Low power design, Wireless sensor network, Smart instruments, Portable instrumentation

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1. Introduction

Handheld digital multimeter (in the following DMM) is probably the most diffused electronic instrument. With few tens of dollars it is possible to buy an object able to measure voltages (AC or DC) from mV to over 100V, current from mA up to 10A, resistance from Ω to 10MΩ, capacitance, frequency or even diodes and transistors parameters, still ensuring an overall accuracy in the order of 1.0%FS [1]. Robustness is another factor that has pointed out its success: it is constructed of plastic and shockproof materials, so that it can be used in harsh environment. Even if this kind of portable standalone instruments have been for long time on the market, they have never modified their user interface, made up of a knob and a LCD display showing measurement readout, preserving easiness of use. Usually, no interface is available to link with an external storage device.

On the contrary, data-loggers are more powerful devices, but improvements in technology and features are paid with increased cost and complexity, requiring specialized operators. They not only allow for accurate measurements and provide conditioning stages toward particular sensors (e.g. thermocouples, strain gauges…), but also furnish a link with a data collecting station (usually a PC), that implements versatile but not standard users interface. Often, several intelligent probes are used and data logger becomes a distributed instrument. When measurements points' number grows, cabling becomes a crucial and critical issue. Today, low-cost wireless technologies can be adopted to resolve these problems [2]. For instance, Radio Frequency (RF) communications may be used to avoid wires together with the need of Line Of Sight among nodes. Nowadays available transceivers necessitate of very low transmitting power, so that battery supply may be adopted and electromagnetic compatibility with other equipments present on the field is ensured. As an example, Signatrol [3] proposes a RF-wireless data-logger (operating in the ISM-433 MHz band) with battery supply and a minimum sample rate of 15s, while MicroStrain [4] presents an RF-wireless instrument, operating at 418 MHz, with the capability of several wireless nodes (up to 100) connected in a star topology to a coordinator which is directly interfaced to a PC by Ethernet. Measurement update time is at least 16s and the GUI (Graphical User Interface) is based on web pages. Obviously, these solutions are collocated in a different market area with respect to widespread DMMs and they are focused on different types of applications.

In the present work, authors suggest a simple and effective solution to enhance DMM features without increasing cost and complexity, also with reference to battery life, leading to what they call the Wireless DMM or WDMM. In particular, wireless networking and storage capabilities are added without affecting the "look and feel" of the final device. It can be still considered a DMM, i.e. a simple, robust and low-cost instrument that can be used also from non highly-specialized personnel. Further on, the WDMM can be considered as the basic building block of a simple distributed measurement system.

2. The Proposed Architecture

The only difference in the appearance of a WDMM with respect to a DMM is that it includes an additional knob to choose among the two available modalities:

- "local mode": the instrument works as a standard multimeter without any added functionality;
- "remote mode": the instrument still works as a standard multimeter, but in addition it transmits the data shown on the display in a 2.4GHz wireless network composed by several (up to eight in the application here reported) wireless multimeters connected to a node called "coordinator" in a star topology fashion.

The coordinator acts as the remote display of each node in the network; it includes a selector that allows to choose the WDMM whose measurement is actually shown. In order to make an example, if we want to check the presence or the absence of main supply in several places of large machinery during an installation, we can overtake the problem utilizing simultaneously many wireless multimeters placed in the measuring points and viewing results on the display of the coordinator. This is the standalone modality, which differ from the data-logging one, where an USB link permits to store data on a host system such as a PC or a PDA, as depicted in Fig.1.

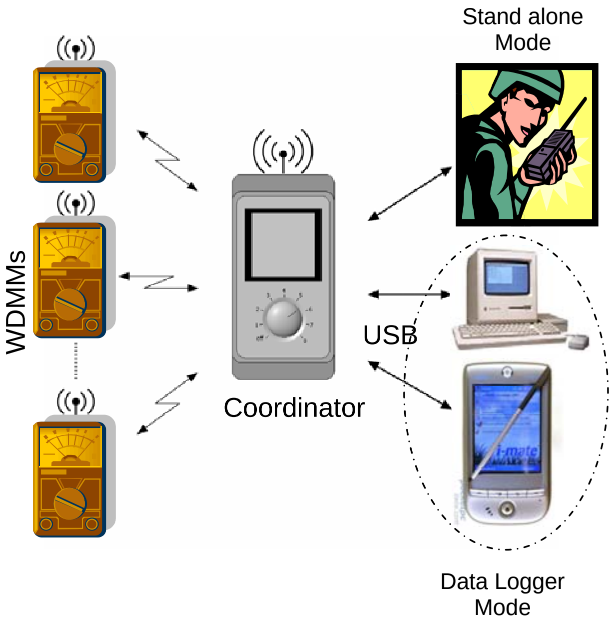
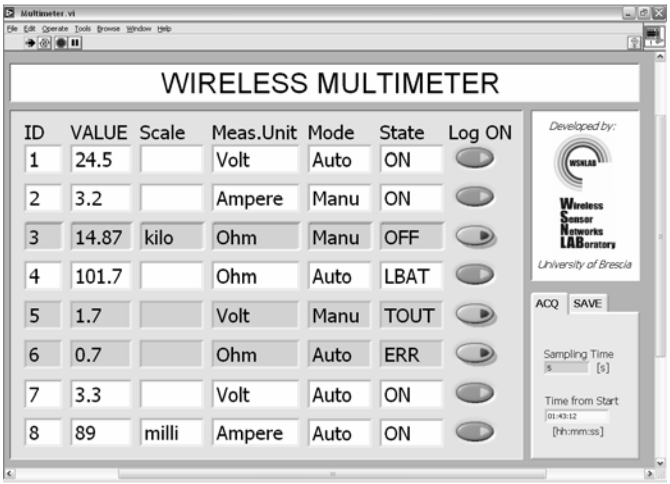


Fig. 1. Wireless multimeters network.

A suitable software has been developed (under LabVIEW environment) to read and store into a logging file readouts from up to eight multimeters, i.e. the maximum number of nodes allowed by the prototype network. Fig.2 shows the graphical user interface.



WIRELESS MULTIMETER

ID	VALUE	Scale	Meas.Unit	Mode	State	Log ON
1	24.5		Volt	Auto	ON	○
2	3.2		Ampere	Manu	ON	○
3	14.87	kilo	Ohm	Manu	OFF	○
4	101.7		Ohm	Auto	LBAT	○
5	1.7		Volt	Manu	TOUT	○
6	0.7		Ohm	Auto	ERR	○
7	3.3		Volt	Auto	ON	○
8	89	milli	Ampere	Auto	ON	○

Sampling Time: 5 [s]

Time from Start: 01:43:12 [hh:mm:ss]

Fig. 2. PC user interface (data logger function).

Besides raw measurement value, information regarding scale, measurement unit and battery status are also provided. As depicted in the figure, it is possible to vary the WDMMs sampling time from 1s to 1h. In addition, the disabled or absent wireless multimeters are grayed out (3, 5 and 6 in the same figure), indicating that data shown is not valid. Logging files can be automatically saved and it is possible to choose binary (more compact) or ASCII file (that can be read by any text editor or spreadsheet applications).

Details about WDMM node, coordinator and wireless protocol are presented in the following.

3. WDMM and Coordinator

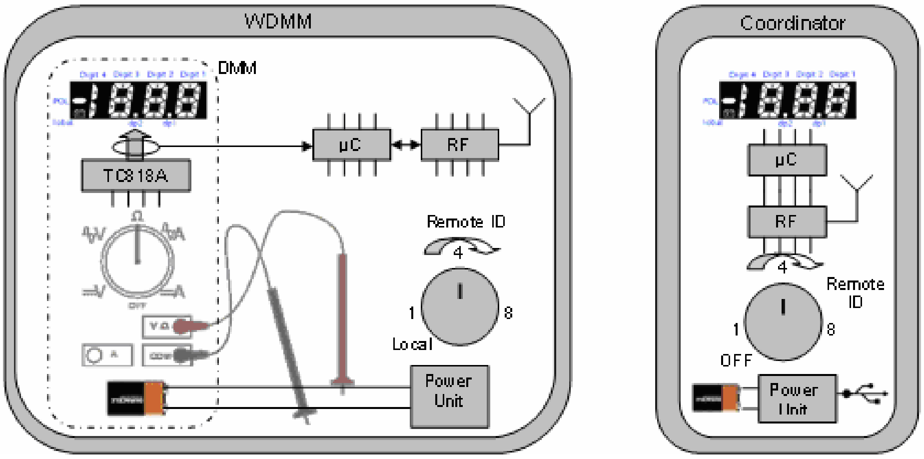
As explained before, what authors propose is a “wireless upgrade” of commercial available DMMs. In this application, a DM155 from Tektronix has been considered; it includes the analog conditioning chain and a single chip (formally the Microchip TC818A) that performs analog-to-digital conversion and drives the LCD.

Circuitries added to the multimeter for RF capabilities are limited to:

- a rotating selector to choose between local and remote mode; in the latter case it also sets the node identification (ID) in the wireless network
- a microcontroller that manages the RF section (PIC18LF452 from Microchip)
- a RF transceiver (MC13192 from Freescale, compliant with the IEEE802.15.4 [5 , 6])

Power supply is drawn from the standard multimeter 9V battery and regulated by a LDO. Battery life is only slightly decreased, since additional devices are turned on just if needed. Readouts are directly grabbed from the connection between the LCD and the MC818A. A suitable comparator block, based upon LP339, translates the triplex voltage levels and the microcontroller decodes their meaning. In this way, when set the “local mode”, the RF extension is completely independent from the DMM itself, while in “remote mode” the WDMM works in a low-duty cycle fashion. The wakeup (i.e. sampling) time is user programmable and the default value is 1s. The readout is 4-bytes long and is composed of four digits, decimal dot position, scale information and measurement unit. A block diagram of the WDMM is shown in Fig.3a.

As previously explained, the coordinator acts as a remote version of the LCD of each node. It includes a rotating selector that is used to select a particular WDMM in the network. For sake of security it is not possible to remotely change the measurement settings, but this feature could be easily added; in this case, the knob on each WDMM should be flanked by electronic switches driven by the on board microcontroller. If it is used in the data logger modality, i.e. it is interfaced with a PC; power supply can be derived from the USB connection. For that reason, the coordinator can remain in the receiving state for most of the time waiting for WDMMs data packets. Otherwise, some form of coordinate sleeping must be implemented so that the coordinator can sleep between successive node transmissions. The transceiver is the same embedded in the WDMM, while the microcontroller is a PIC18F4455 that already has an USB slave peripheral. Since this module is usually connected to power mains it uses rechargeable batteries. The LCD is driven exploiting the three-state mode of the microcontroller ports. A block diagram of the coordinator is shown in Fig.3b.



(a) (b)

Fig. 3. Wireless multimeter block diagram.

4. The Wireless Protocol

The MC13192 RF transceiver is compliant with the physical layer of the IEEE802.15.4; it has been chosen thanks to its low cost and diffusion. It works in the ISM free band around 2.4GHz and offers a gross data rate of 250 kbps. A simple proprietary protocol has been implemented having in mind semplicity and portability. For this reason, a simple star topology has been realized at the network level. As regards the Medium Access Control layer, a sort of slotted CSMA/CA has been adopted. When a coordinator turns on and wants to start a new network, it looks for a free channel evaluating the floor noise and sending a ping packet to verify if other coordinators are already present. This is a simplified implementation of the active scan of the IEEE802.15.4. After that it periodically (multiple of sampling time) sends a beacon packet, that is used by WDMMs for synchronization purposes and that contains the Network IDentifier (NID), that univoquely associates the coordinator and its child nodes. If the channel becomes too noisy, it scans a list of pre-programmed channels looking for a new one. Depending on the availability of mains power supply or not, the time between two successive beacons is divided into an active and sleep period; in the former one the coordinator stays in the receiving state waiting for nodes to join or send data, while in the latter it turns off to preserve battery life. On the other side, when a node turns on it sends a join request waiting for the coordinator answer, that contains the NID and the time it must sleep before the next data transmission. The node goes in a low power state until its time slot is reached, then it sends a data packet. The datagram is composed of 19 bytes, including the PHY Header (6 bytes), the Manifacturer ID (2 bytes), the User ID (1 byte), the Network ID (1 byte), the readout (4 bytes), the battery status BATT (1 byte), a progressive sequence number SQN (1 byte), a protocol type field (1 byte) and a Frame Check Sequence FCS (2 bytes). After sending the data, the wireless multimeter waits for the ACK message from coordinator that it is formed by 16 bytes (PHY Header (6 bytes), the MID (2 bytes), the UID (1 byte), the NID (1 byte), the time must elapse before next data packet (2 bytes), a progressive sequence number SQN (1 byte), a protocol type field (1 byte) and a Frame Check Sequence FCS (2 bytes)). In this way, sampling time can be easily changed and adaptively updated to take into account clocks drift. If nothing is received, the node tries again up to four time (it depends on the time slot duration and power consumption) and finally goes to sleep; in order to prevent desynchronization it waits for the next beacon. If is not possible to reach the coordinator, the rebinding procedure is issued and available channels are subsequently scanned. Datagrams are as short as possible to decrease power consumption; in addition, CSMA is not implemented for acknowledge packets that immediately occur after data sending. A brief resume of datagrams exchange is reported in Fig.4.

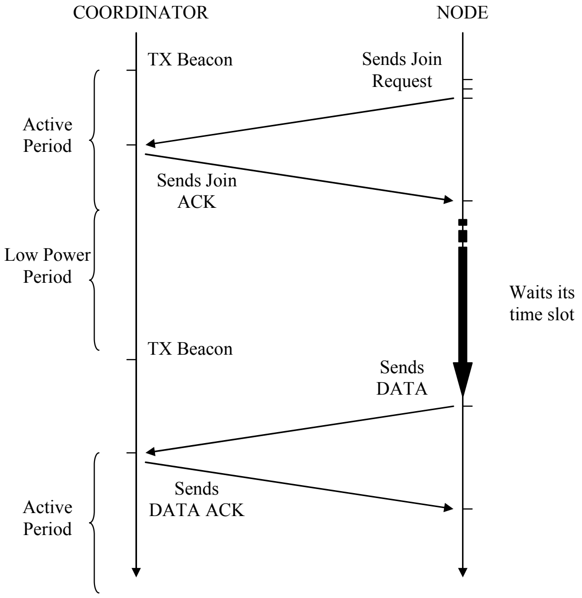


Fig. 4. Data exchange temporal evolution.

Some considerations about power consumption can be done. As regards the MC13192, it can be in one of the following conditions [7]:

- DOZE: the device is disabled except the clock, that is used to wakeup all other circuitries; the power consumption is limited to about 35 µA
- IDLE: the logic control is switched on but the radio section is powered down (0.8 mA)
- TRANSMIT/RECEIVE: all the circuits are switch on and the device is ready for transmitting or receiving data (~ 32 mA, but depends on power output level).

The current consumption of the tranceiver only has been measured as the voltage drop across a 1.8Ω shunt resistor amplified by an instrumentation amplifier (INA110 with Gain=100) and acquired with a digital oscilloscope (LeCroy LT374M); a waveforms example is shown in Fig.5. Ignoring initial binding phase, a roughly energy budget can be computed supposing a sampling time of 1s; the average consumption in the TX phase is ≈20µA, in RX phase is ≈35µA, in IDLE is ≈1µA and all the rest of the time is spent in DOZE mode requiring about 35µA [8].

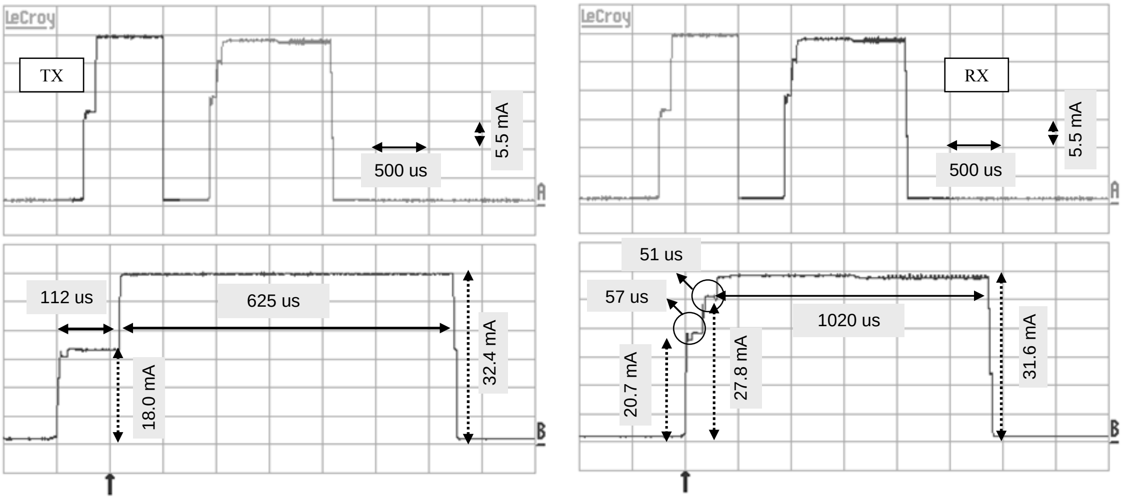


Fig. 5. MC13192 power consumption during the TX and RX phase.

About the rest of circuitry, the TC818 requires 634.4 ms to complete an acquisition; it spends 122.1 ms in the startup phase, it needs 488.3 ms to end the conversion and 24 ms to send the measure to the LCD display. All through this period its current consumption is about 970 µA; supposing T=1s, its average consumption is about 615 µA. Since the microcontroller determines start of conversion (i.e. it powers up the TC818A), it must be awake; to lower the consumption it has been chosen a dual clock solution. In other words, its clock is set to 32 kHz (634.4 ms @ 30 µA) until the TC818A has completed a single conversion, while its clock arises to 20 MHz (34ms @ 3.65 mA) during the triplex signal acquisition and data TX/RX phases. After that, it goes in sleep mode, requiring typically less than 1 µA. The microcontroller average consumption is about 140 µA. Thus, all the system requires less than 1mA; from another point of view, it means that the wireless capability requires only one third more energy than consumption of traditional DMM and advantages offered greatly overcome a slightly shorter battery life. Considering a 9V battery power supply (with a capacity of 1.2 Ah), each node has an autonomy of about 1200 h. On the contrary, the coordinator stays in the RX/TX state for all the active period, leading to a considerable shorter life. However, better results can be obtained if low sampling frequencies are considered.

4. Conclusions

In this work the authors have presented the realization of a simple distributed measurement system based. It exploits low cost RF transceivers operating in the free ISM band around 2.4GHz; such modules have been used to join advantages of traditional DMM with a wireless radio link. The proposed architecture consists of an upgrade module that can be applied to any commercial devices. It has been shown that batteries can be used still ensuring an adequate maintenance scheduling. In addition, the availability of a USB link toward a PC allows to realize a data logger whit data storage and analysis capability.

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Guide for Contributors

Aims and Scope

Sensors & Transducers Journal (ISSN 1726- 5479) provides an advanced forum for the science and technology of physical, chemical sensors and biosensors. It publishes state-of-the-art reviews, regular research and application specific papers, short notes, letters to Editor and sensors related books reviews as well as academic, practical and commercial information of interest to its readership. Because it is an open access, peer review international journal, papers rapidly published in *Sensors & Transducers Journal* will receive a very high publicity. The journal is published monthly as twelve issues per annual by International Frequency Association (IFSA). In additional, some special sponsored and conference issues published annually.

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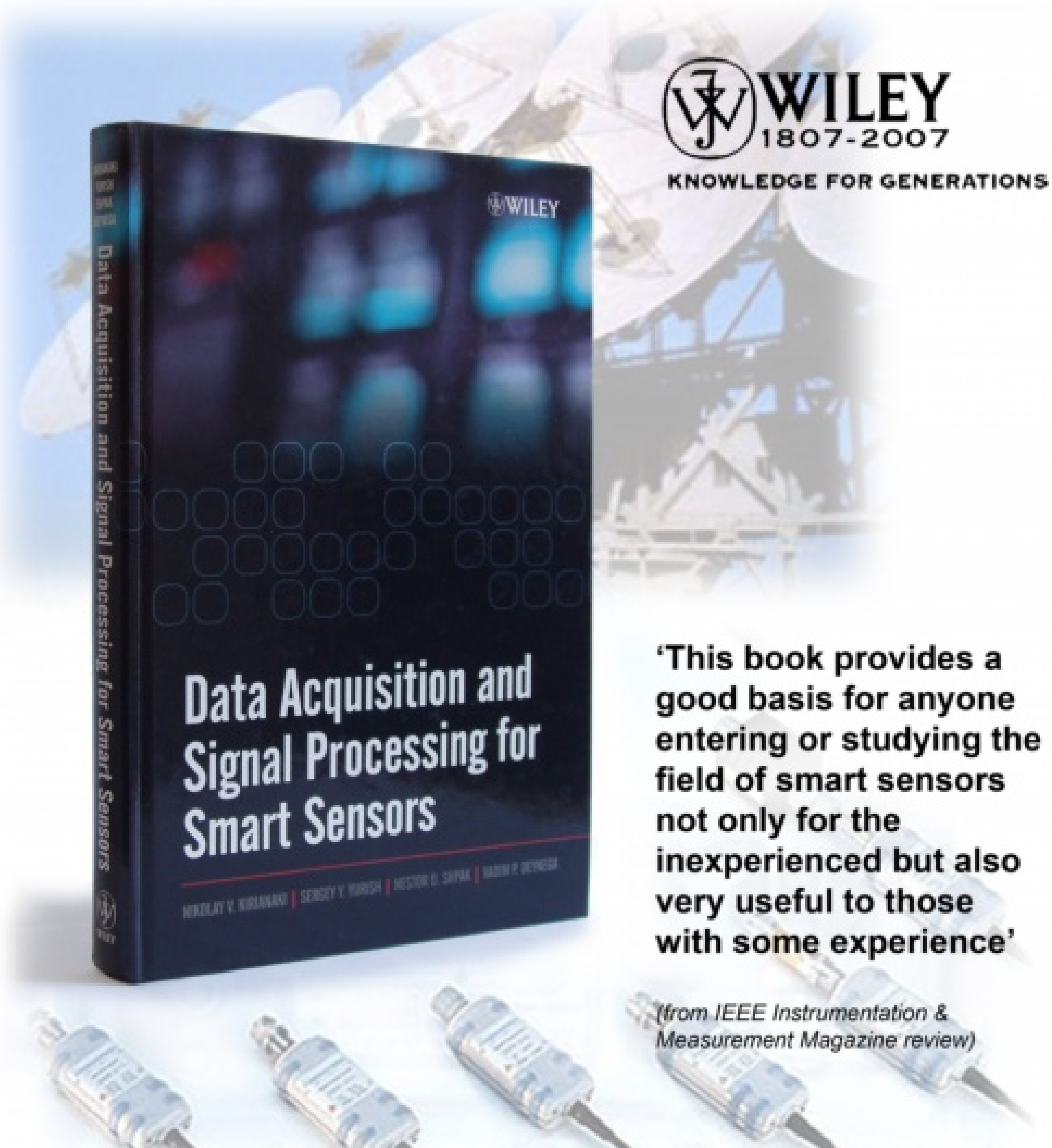
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