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REMOTE METERING IN PUBLIC NETWORKS

L. Ferrigno[1], R. Morello[2], V. Paciello[3], A. Pietrosanto[3]

1) *DIEI University of Cassino, Cassino, Italy, ferrigno@unicas.it*
2) *DIIES, University Mediterranea of Reggio Calabria, Reggio Calabria, Italy, (✉ rosario.morello@unirc.it)*
3) *DIIn, University of Salerno Fisciano (SA), Italy, vpaciello@unisa.it*

Abstract

New research trends in energy grids and water networks push toward ICT solutions for allowing remote metering of consumption. In the paper, after an introduction to the European Standards on smart metering, two visual sensors thought to solve typical metering problems in water public networks are described. Particular detail is given hardware and software solutions and the perspective of integration with analog gas and electric energy metering devices.

Keywords: Automatic Meter Reading (AMR), Remote Metering, Advanced Metering Infrastructure (AMI), Smart Metering, Visual Sensor.

1. Introduction

In December 2008, the European Union approved an agreement on the so-called "climate and energy package 20-20-20'', which foresees, by 2020, many targets on several fronts: a 20% reduction of greenhouse gas emissions, a 20% increase in energy efficiency and the achieving of share of 20% in alternative renewable energy; the U.S. government has also moved along the same lines [1, 2]. The research on innovative Automatic Meter Reading (AMR) systems and Advanced Meter Infrastructure (AMI) plays an important role in the treatment and billing consumption data of main public utility services such as electricity, gas and water.

Through the architecture of remote management of consumptions, it is possible to do in remote all the actions that were previously possible only with the intervention of readers, or teams of technicians: reading data, enabling of the supply, fulfilment of power switches, management of the takeover, etc…. Even if we did not want to give up readers, suitable architectures of remote metering could both greatly improve their efficiency and reduce the impact on the users. Since the remote reading can also be made at short intervals, the user has to pay only the energy actually consumed and in this way he excludes any presumed data. The knowledge of the consumption profiles in real-time, enables those who manage the energetic networks to create mechanisms of greater dynamism, flexibility, decentralization and interactivity in the management of the networks themselves (smart-grids); in addition, it also provides the user with the ability to have greater awareness of what is consuming. Also it is possible to implement numerous services of high added value as the automatical detachment of loads to reduce the consumption peaks... Higher frequency of detection of the readings can finally allow to easily identify both losses on the private network user downstream of the meter and losses related to failure of the measuring instrument, which would involve missed billings with economic losses for utilities.

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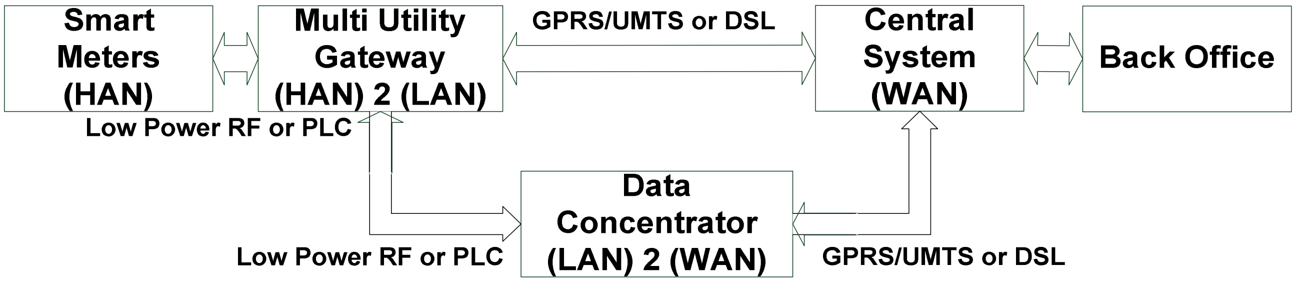

Fig. 1. An architecture of smart metering.

In order to facilitate the development of architectures for smart metering and to avoid competition between different technologies, in March 2009 the European Commission gave a mandate to CEN, CENELEC and ETSI to develop the standards needed to implement an open architecture of interoperable Smart Metering systems (M/441 EN) [3]. The European project Open Public Extended Network Metering (OPEN Meter) is an invited partner to the mandate of standardization as the project's objectives are in line with the mandate. The project results will be a series of open standards, without rights on standards and will be available to all stakeholders; the project includes more than remote reading service for utilities, new energetic services to added value; measurement devices become nodes of communication networks [1]. Governments, through national energy regulators, are requiring utilities to realize the architecture for Smart Metering. Concerning Italy, in October 2008 the law 155/08 of the Authority for Electricity and Gas made the use of the latest generation measurement devices compulsory, which are essential for reading and remote management [4]. The European Directive 2004/22/EC, known as the MID (Measuring Instruments Directive), regulates ten different categories of instruments and measurement systems and gives particular attention to software for metrological aspects and to data treated by AMR and AMI architectures [5]-[6]. The relationship between users and utilities will result as deeply changed in the direction of a greater transparency and less discords, if the AMR and AMI architectures will be designed according to these standards.

Briefly, an architecture for smart metering (see Fig.1) is provided with a bidirectional communication interface and transfers the data from meter readings to a central system that stores them and makes them available to back-office systems of utilities. The connection in the Home Area Network (HAN) between home devices and the smart meter (or between the smart meter and a metering gateway which acts only as a single communicator) can be performed on protocols in power line carrier (PLC) as for electric energy, or on low power radio frequency (RF) protocols. The communication of data points to the central system of data collection can be done directly with WAN protocols (Wide Area Network) typically GPRS or DSL, or, if we use data concentration, with PLC and RF Low Power. The data concentrators communicate with the central collection system through WAN protocols.

Remote-reading of consumption is now a reality in many European countries and outside Europe mostly as regards the provision of electricity. This has been possible mainly thanks to the gradual replacement by the utilities of old electro-mechanical meters in favor of new electronic meters. The measured data from the smart meter are sent to the data concentrator, often placed in the substation of MV/LV electric transformation, using PLC technology, while concentrators communicate with the central collection system using GPRS, DSL, or MV-PLC. The project "TELEGESTORE" of ENEL is one of the most innovative and ambitious project in the global field for smart metering; the project has involved the replacement, completely free for customers, of 30 million of previously existing electromechanical meters with new electronic devices and the establishment of a hardware and software system architecture for remote-reading and remote-management [7].

Actually, remote reading is widespread for electricity, but it is not so widespread for water and gas networks.

The architectures for AMR and AMI for the supplies of gas and water are much less common than in the electricity sector, but they are under development; most of the counters, especially those in the water service, are still electromechanical and are installed in areas not easily accessible, where very often there is no electricity. For remote reading some AMR architectures for water use counters having simple "pulse" interfaces. These interfaces use a pulse generator to “reed switches”, which, in combination with one of the magnets installed in the watch counter, emits a number of output pulses proportional to the amount of water flowed. These types of counters have basically three types of problems:

1) may generate spurious pulses when subjected to mechanical stress;

2) can be easily tampered with by an external magnet, and then provide a wrong number of pulses;

3) it is not possible to discriminate the pulses due to backflow of water; these pulses should be subtracted from the general calculation because they are generated by a rotation in the opposite direction of the mechanical counter. To solve these problems, pulse generators of static type have been created, involving the use of on-board microcontrollers.

In addition, the interface architectures that use the pulse interface (static or “reed switch”) require a complete replacement of old electromechanical meters in favor of new water meters with a pulse interface, which would involve high costs by the utilities or users. Nevertheless, the problem of contentions is not completely resolved, as there is not a "certification" of the remote reading; in fact it is always possible to read an error or incorrect association between the measured data and the user’s real consumption. In light of the above, there comes the need to create a device for AMR and AMI architectures which, even though avoiding the replacement of old-electromechanical counters, automatically sends the consumption readings and solves the problem of contentions.

The visual sensor node, object of the present work, allows implementing the architecture of remote metering of the handheld, mobile or fixed network AMR type.

The on-board digital micro-camera is able to capture an image of the totalizer of the user counter, thus allowing the remote transmission of the measurement data via a wireless channel, permitting the introduction of "instant billing", and ensuring, at the same time, a sort of "certification of the measurement". Indeed, video-remote-metering allows to insert the image of the totalizer in the printing of the bill, certifying the accuracy of reading and protecting both the managing company against any claims and the user from possible mistakes in measurement data. Some communication problems be present where the electromagnetic waves are weak, for example in the case of installation in manholes or underground [17, 18].

In the past, the authors used either Bluetooth modules or WiFi modules [8] for short-range communication such as communication between smart meters and data concentrators [9]. Then, a GPRS module has been adopted for long-range communication in a prototype suitably designed for great industrial or public users interested in monitoring their own consumption. In the paper the authors describe the work made to redesign the sensor architecture with the aim of: i) reducing cost and dimension of the wireless module for the need of home users; ii) trying to frame it in the OPEN Meter European project. After an introduction on the MID directive, the prototypes of a visual sensor node featured with either RF or GPRS wireless module, suitable for short- and long-range communication, are described in detail.

2. Requirements of mid directive

If the measurement results are obtained using a measuring instrument, and if for reasons of public interest a minimal degree of accuracy of the measurements is required, the measuring instrument is made in accordance with legislative requirements that guarantee the minimum degree of precision in the normally predictable operating conditions.

In order to ease the task of proving conformity with the essential requirements and to enable conformity to be assessed, it is desirable to have harmonized standards. Such harmonized standards are drawn up by private-law bodies and should retain their status as non-mandatory texts. To this end, the European Committee for Standardization (CEN), the European Committee for Electrotechnical Standardization (CENELEC) and the European Telecommunications Standards Institute (ETSI) are recognized as the competent bodies for the adoption of harmonized standards in accordance with the general guidelines on cooperation between the Commission and the European Standardization bodies signed on 13 November 1984.

The MID directive has been emanated with the aim of providing a harmonized standard for testing the above-mentioned instruments. The scope of this directive is to guarantee users a high level of safety and reliability of the measuring instruments, protection against data corruption, ensuring in the meantime a free circulation of certified measuring instruments within the European Union. In other words, MID can be seen as a directive entered into the "new strategy" aimed to create an internal market for measuring instruments subject to legal metrological control, by setting: (i) essential requirements and conformity assessment requirements, but always maintaining the high level of consumer protection currently in force, and (ii) the mutual recognition between Member States of the results of conformity assessment. The essential requirements are seen not as design specifications, but as performance requirements: as such, they are for the most part regardless of technological development thus significantly reducing the need for future adaptation to technical progress.

The MID directive is related to ten categories of measuring instruments, whose requirements are indicated in ten annexes from MI-001 to MI-010. Among them, annexes MI-001 (water meters), MI-002 (gas meters and volume conversion devices), and MI-004 (heat meters) fall into the scope of the present paper since they involve meters that can be subjected to automatic meter reading procedures and for which the proposed add-on visual sensor can be adopted.

For all ten categories, the MID defines classes of climatic conditions, mechanical environments, electromagnetic environments in which normal operation of the considered meter and compliance with the accuracy requirements reported in the respective annexes must be guaranteed.

As for the climatic conditions, four classes of possible environments are defined: they come from 5°C to 30°C of the first one to -40°C to 70°C of the latest one.

Depending on the installation, three classes of mechanical environments are defined: M1, this class applies to instruments used in locations with vibration and shocks of low significance, e.g. for instruments fastened to light supporting structures subject to negligible vibrations and shocks transmitted from local blasting or pile-driving activities, slamming doors, etc. M2, this class applies to instruments used in locations with significant or high levels of vibration and shock, e.g. transmitted from machines and passing vehicles in the vicinity or adjacent to heavy machines, conveyor belts, etc. M3, this class applies to instruments used in locations where the level of vibration and shock is high and very high, e.g. for instruments mounted directly on machines, conveyor belts, etc.

As far as the electromagnetic environments are concerned, depending on the installation, three classes of electromagnetic environments are defined. E1: this class applies to instruments used in locations with electromagnetic disturbances corresponding to those likely to be found in residential, commercial and light industrial buildings. E2, this class applies to instruments used in locations with electromagnetic disturbances corresponding to those likely to be found in other industrial buildings. E3, this class applies to instruments supplied by the battery of a vehicle. Such instruments shall comply with the requirements of E2 and the following additional requirements: voltage reductions caused by energizing the starter-motor circuits of internal combustion engines; load dump transients occurring in the event of a discharged battery being disconnected while the engine is running. As for the visual sensor proposed all the climatic ranges, the M1 mechanical environment, and the E1 and E2 electromagnetic environments apply. As far as the electromagnetic environments are concerned they impose the immunity of the meter under some conducted and radiated disturbances typically presents in civil and industrial environments. The following sets of disturbance should be at minimum considered: power voltage variation, bursts, electrostatic discharge, electromagnetic susceptibility.

As for specific climatic, mechanical and electromagnetic disturbances to be considered, MID adopts requirements provided in the International Organization of Legal Metrology (OIML) standards specifically provided for the considered meters [11, 16].

As an example, as for the E2 environment, if the meter is supplied by a DC battery, the power voltage variation disturbance has to be considered. A variation in the DC battery power supply has to be provided. The objective of the test is to verify compliance with the provisions in 3.2 under conditions of varying DC power supply. The test procedure is in brief described in the following. The meter error (of indication) shall be measured with the maximum and the minimum operating voltages of the battery, as specified by the water meter supplier, applied throughout the test. As for the maximum allowable variations, all functions shall operate as designed and all errors (of indication) measured during the application of the influence factor shall be within the maximum permissible errors of the upper flow rate zone.

As for the proposed add-on device, it can be considered for the application of the MID as a measurement and transmission unit connected to the water, gas or thermal energy meter. This imposes that this unit has to accomplish the requirements of the MID directive in terms of climatic, mechanical and electromagnetic environments. To this aim on the one hand the development and realization of the add-on smart sensor has to be executed taking into account the MID requirements, and on the other hand compliance with the MID requirements has to be guaranteed with suitable tests in MID-notified laboratories.

3. Visual sensor nodes

The authors designed two different prototypes, the former thought for big users, and the latter for the smaller ones. This differentiation drives the choices in terms of cost and communication capabilities. Great users often need to know their own consumption readings with a frequency higher than invoicing. Moreover, their high consumption can justify a higher cost of metering. Small users are only interested in avoiding that readers come to their home and that invoicing be based on measured rather than foreseen data, but are rarely interested in automatic monitoring and do not want either pay fees or cost of installation. As a consequence, the authors have had to think of two different solutions with different cost and communication capability.

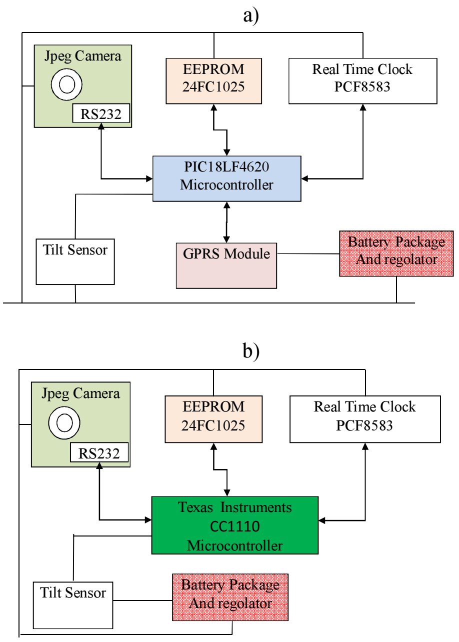

Fig. 2. Block diagram of visual sensor:
a) with GPRS module, b) with RF Module.

The architecture of a single sensor node is based on seven modules: processing unit, memory, real time clock (RTC), sensing hardware, communication module, tilt sensor and battery power supply (Fig. 2, a).

The first solution was based on a GPRS module (plus SIM-data communication) which is responsible of a relevant part (70%) of the whole price and causes a fixed cost of data communication.

As a consequence, with the aim of satisfying the requirements of smaller users, the second solution has been featured with a low-cost communication module which uses a protocol that operates in the ISM band.

As a result, in the second solution the visual node is based on six modules: processing unit, memory, real time clock (RTC), sensing hardware, tilt sensor and battery power supply, as in this case the communication module is integrated in the microcontroller unit (Fig. 2, b).

The sensor node can operate passing through the following states:

(1) standby-state, (2) normal-state (3) connection-state (4) sensing/communication-state. Transitions from one state to another depend on the network topology and on the implemented measurement procedure. The visual node was programmed by the authors to follow the following procedure:

(1) When idle, the standby-state is managed by holding the microcontroller in a sleep-mode, while all the other peripherals are turned off, with the exception of RTC.

(2) Sometimes, with a period defined by the designers, the microcontroller passes in the normal-mode a state where the current consumption becomes significant (an average of about 35 μA, with a period of 1 second); in this state, the digital camera is still turned off, the microcontroller operates in the run-mode, the RF module is powered up and so the sensor node can start the connection with the network in order to find out whether a gateway asks for consumption data. If so, the node passes to the state (4), else it comes back to (1);

(4) During the sensing/ communication state the counter panel image is acquired. The microcontroller, the RF communication module and the digital camera are powered-on, the electrical current consumption is about 90 mA. In this phase the microcontroller sends a JPEG image to

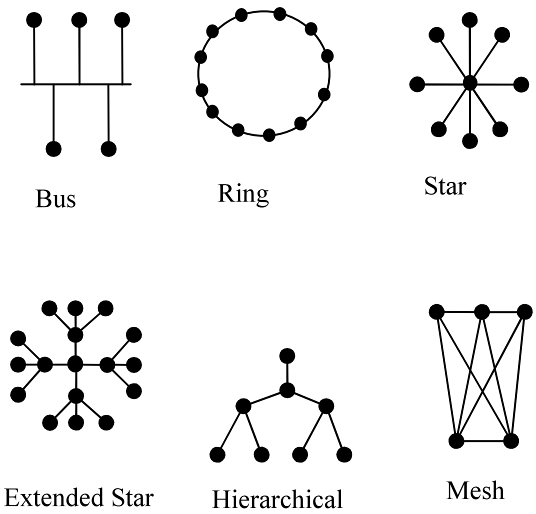

Fig. 3. Different types of networks topology.

Fig. 4. The reference climatic chamber selected for the MID tests.

the communication module to be sent to the gateway;

The entire procedure, consisting of the wake up phase, connection phase and communication phase, takes about 60 s.

3.1. Hardware

Heart of the sensor node is the processing unit; it is composed by a Texas Instruments C1100 low power microcontroller. The microcontroller device can operate in low power consumption mode (sleep mode); in the sleep mode the normal I/O processor activities are stopped and the maximum electric current required by the device is less than 400 nA at 3.3V. The microcontroller integrates a RF low power module (Frequency bands: 470-510 MHz and 950-960 MHz). This module is the key of the communication link.

The memory module consists of a 1 Mb EEPROM (24FC1025) with a two-way bi-directional serial interface-I2C. The EPROM with I2C serial interface has been chosen to reduce at minimum the digital I/O pins used in communication with the microcontroller.

The calendar clock installed in the sensor node is the PCF8583 manufactured by Philips Semiconductors. When the acquisition occurred, it is possible to associate the date and time to the image. This is a "clock/calendar" with 240x8 bit of RAM in CMOS technology and two-way bi-directional serial interface-I2C.

The sensing module is a JPEG Camera (C328) which has two chips: the visual sensor OV7640 and the compression/serial-bridge chip OV528. The sensor OV7640 allows different resolutions from 80x74 to 640x480 pixels, and allows different choices for colors: from a 2-bit grey scale to 16-bit color. The OV528 is a controller chip with JPEG hardware compression of the scanned image, a memory that allows to temporarily store the compressed image acquired and a RS-232 (TTL logic) which enables the transfer of information to an external device (host). At 3.3V it draws less than 60 mA in the active state and less than 20 mA in standby or suspended mode. The tilt sensor is a mechanical movement sensor which may bring a microcontroller out from the sleep mode with no power requirement. Most of the components used require a power supply voltage of 3.3V DC, the module clock/calendar is also equipped with an additional backup battery model CR2032, 3V DC voltage. The battery pack consists therefore in a single high-capacity battery (9V DC) input connected to a voltage regulator that provides the power supply to devices connected to the visual sensor.

3.2. Software

The microcontroller software was developed in C language, using the integrated development environment provided by Texas Instruments. The software implements the operating states described above. In particular two libraries have been implemented, one for communication with the camera and the other one to communicate with the RF module. In particular, the RF library controls the RF module which offers all the services available in wireless networks.

4. Network topology

The request from people with small energy use is to minimize the cost of metering and reduce the number of accesses for device maintenance. The company operator should have access to the metering device no more than once in five years. For this reason, as far as the proposed smart metering system is concerned, the meter battery should grant a five-year life, together with small dimension and cost. These specifications influence the design of the wireless network topology.

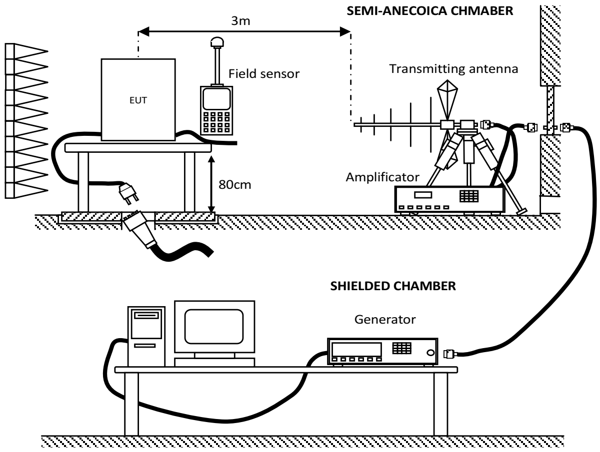

Fig. 5. The set-up adopted for the radiated immunity MID tests.

There are six different common topologies: Bus, Ring, Star, Extended Star, Hierarchical, and Mesh (see Fig. 3). One of the most popular topologies for the network is the star and extended star topology. It is easy to set up, it is relatively cheap and it creates more redundancy than the Bus Topology. The Star Topology works by connecting each node to a central device. This central connection allows us to have a fully functioning network even when other devices fail.

The Extended Star Topology is more advanced. Instead of connecting all devices to a central unit, sub-central devices are added to the mix. This allows more functionality for organization and subnetting - but it creates points of failure too.

With the aim of satisfying the design specification in terms of battery life, the authors chose the star topology. Indeed, except for the central node, this topology should assure the least consumption: only when the sensor node is in run mode and establishes a link with the central device the consumption is high; in all other cases, the consumption appears to be minimum. As for the central device, the authors were thinking about a mobile device held by the company operator (reader), which will be part of the network only when the operator comes to gather meter readings. Considering the results shown by the experimental test, the proposed solutions can be used for the two kinds of consumers. However, the specifications are satisfied and the management cost is low. On the other hand some test on the batteries must be made to ensure the required lifetime (choose the right battery capacity in order to achieve the desired life time).

5. Set-up realization and performance criteria selection

Once the prototype add-on has been realized, tests to be executed to accomplish for the MID requirements can be finally carried out. To this aim a couple of activities is preliminarily required: (i) the realization of the measurement set-up, and (ii) the selection of suitable figures of merit able to show the performance of the realized device that could be reduced during immunity tests.

(i) As for the first activity a simple network realized with a visual sensor and a PC has been realized. The smart add-on sensor has been linked to a MID certified traditional water meter. In this way the necessity of respecting the MID requirements is due only to the proposed sensor. As for the measurement certification scheme, the proposed device can be seen as the sum of some operating elements: (a) the sensor, (b) the memory, (c) the power supply and (d) the transmission unit. At this stage only the effect on the (a) to (c) components has been investigated. To this aim, every time the PC requires a measurement, the sensor executes a photo and sends it over a RS232 channel which is the gateway of the RF module. After this stage, the climatic and the electromagnetic tests required by MID have been planned. As far as the climatic tests are concerned, the reference climatic chamber presented in Figure 4 has been adopted. In the climatic chamber both temperature and relative humidity are controlled. The temperature is controlled by a PID system that uses two PT100 thermal resistances; relative humidity is controlled by a reference psicometer.

The electromagnetic test related to the E1 and E2 environments required by MID is realized in a suitable shielded semi-anechoic chamber certified for measurements up to 18 GHz. It allows the execution of the electrical safety tests and electromagnetic compatibility tests with reference to international and European standards for the CE marking. In Figure 5 the set-up adopted for the radiated immunity MID tests is shown.

(ii) As far as the selection of suitable figures of merit is concerned, this represents a hard task of the paper. MID requires the evaluation of the maximum performance error of the meter both in the nominal condition and during the disturbances. It is evident that several quantities and several testing methods are involved depending on the selected meters. In particular, as for water meters the evaluation of the water flow is involved, while gas volume and heat energy have to be evaluated for gas and heat meters respectively. The realized visual sensor does not execute directly the above cited measurements but it takes a picture of the counter status at measurement time. This imposes the creation of other figures of merits able to verify the MID requirements.

This task has been executed considering two consecutive tasks: Finding an objective image quality index and the choice of a measurement threshold.

A number of indexes capable of estimating the quality degradation of a picture introduced by digital coding algorithms have been proposed in literature. They are usually divided into subjective and objective classes. Subjective methods, as defined in the ITU-R BT 500 recommendation are very expensive and time-consuming [9]. In a previous paper the authors have shown that very simple algorithms based on structural similarity give surprisingly good image quality prediction for a wide variety of image distortions. The following algorithms seem to be the most promising: Mean Squared Moran Error (MSME), SSIM, CW-SSIM [9]. In [9] it has been shown as the CW-SSIM shows a better output value and a lower standard deviation value, it could be a suitable reference metric for the image quality index.

As for the choice of a threshold, once the better image quality index is chosen, the next step concerns the definition of a suitable threshold related to the image quality level required by the application under consideration.

In remote metering applications the acquired image must still allow the counter digits and serial number to be read. Measurement reading is often entrusted to suitable software modules, capable of reconstructing the measurement information starting from an optical character recognition (OCR) procedure. A received image can be considered good enough if the OCR software is able to detect these digits correctly. Hence, common OCR software such as Scansoft "Omnipage pro 14.0" was adopted.

6. Conclusions

A low cost, low power RF prototype sensor node has been developed. The results of the characterization and testing of the system show good repeatability and acceptable time responses. The authors have also described the efforts made for tackling the problem of making remote metering devices compliant with European standards such as MID and OPEN Meter.

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