

Project Codename — “Sensor Data Remote Acquisition”

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Abstract—Remote sensor’s installation and data acquisition are rapidly growing technical field. Data sensing in a variety of ways, transmission, collection, storage, analysis and resulting control, alarms, statistics etc. require knowledge in different fields to achieve the best and effective result. Different specialities professionals are involved in all stages from design till installation and over. “Meaning and importance of sensor data“, “energy efficiency“, “the most effective way for data transmission” etc. are common questions during system development and article share some practical experience about common questions.

Index Terms—Data remote acquisition, communication, sensor, energy efficiency.

I. INTRODUCTION

Physical phenomena data sensing in variety of ways, data collection, storage, analysis and resulting control, alarms and statistics etc. require knowledge in different fields to achieve the best and effective results.

System design, installation and following data acquisition and processing work involve professionals from different fields. All team members must have some knowledge in related field to participate in teamwork.

Today all around the world higher education attempt to give deep knowledge in narrow field. System design team professionals with deep knowledge and practical experience only in some narrow field, design ineffective system's time after time - complicated solutions instead of simple and thus more reliable, special training is necessary to work with the system, complicate servicing etc.

One can look on upraising Internet of Things as solution or systematization of sensor remote data acquisition systems and methods. Internet of Things (IoT) is just a name with meaning “a global network infrastructure, linking physical and virtual objects through the exploitation of data capture and communication capabilities. It will offer specific object-identification, sensor and connection capability as the basis for the development of independent cooperative services and applications. These will be characterized by a high degree of autonomous data capture, event transfer, network connectivity and interoperability” [1]. This is one of known definitions, starting by K. Ashton [2]. More or less all IoT definitions sound like a “wish-list” in a bit. This doesn’t mean that the whole idea must be blamed or is wrong, no. The whole “thing” is so big that definition can be only descriptive. Definition cannot be a tool to develop effective system, definition can help to describe such system.

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There are attempts to systemize IoT [3]. If implemented, IoT reference architecture can help to develop compatible designs but still all team members must have some knowledge in related field and good understanding about human-machine interaction and ergonomics

Before any design and during it, the most important are answers to the questions:

- Why we need to know that physical phenomena data?
- Does the data we have read are the best representation off the physical phenomena?
- How we translate these data to human understanding?
- The meaning of data - influence on environment, influence on health, influence on knowledge?, etc.

After these leading questions come more detailed questions:

- How physical phenomena data will be translated to electrical signals?
- How frequently data must be read?
- How data will be stored, for how long period?
- Does the system can be applied without special training?
- Qualifications of system servicing personal?
- Total cost of ownership (TCO)?
- Does the TCO is worth for acquired data importance?
- Reliability? etc.

Below in brief are described remote sensing system components and some experiences from developed systems. Simpler system always is better. Author hope that described could be helpful.

II. REMOTE SENSING SYSTEM COMPONENTS

A. Wireless Communication

Mainly remote sensor data acquisition is done through wireless connection. So the question is: what is the best wireless system for our needs? Question is similar to later question: what computer operating system we choose to represent and store data. None of them are easy to answer question.

Today exist many wireless communication standards. Some of them are shown on Fig. 1. Others like Wireless M-bus (EN 13757) or Bluetooth Low Energy are not tested yet for field sensors and aren’t observed here.

Each wireless system has own evangelists and promoters and, according to their words, “This system is the best”.

Before we trust, we tested several of them on a variety of installations and for variety of the tasks.

As known, wireless communication can be simplex (one-directional) or half-duplex or full-duplex (bi-directional) systems. Mainly half-duplex systems are used since they offer simpler and cheaper technical solutions: systems use a single carrier frequency and transmission and receiving takes place alternatively.

Field sensor data mainly are sent over simplex system because simply there are no actuating devices.

Other sensors (readings from electro-technological devices, for example) typically send data over duplex communication.

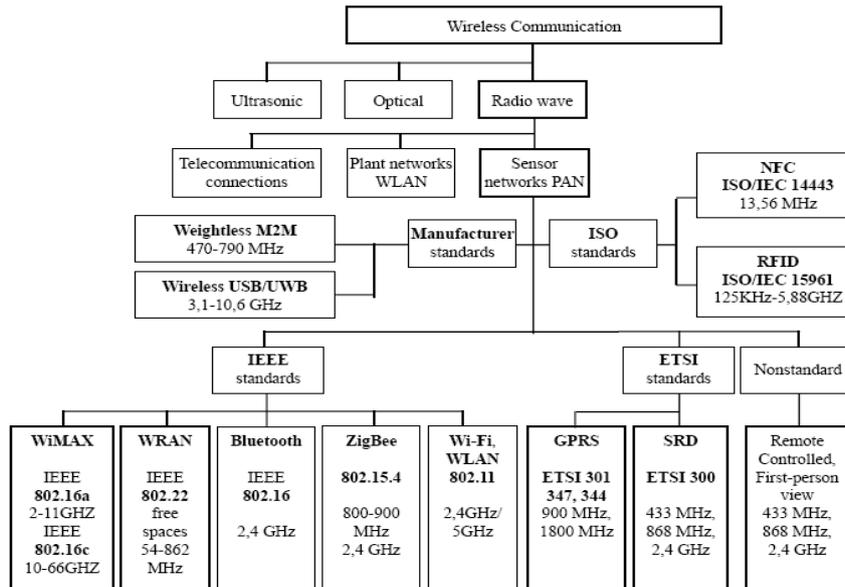


Fig. 1. Wireless communication classification by carrier, network, standard and communication protocol.

It isn't easy to choose the most suitable wireless communication tool according to shown on Fig. 1.

The first important argument is communication distance. For example [4]:

- NFC <5 cm,
- ZigBee <100 m,
- Wi-Fi <150 m,
- 433 MHz UART <1000 m,

Figures are very relative, for outdoors, direct sight and depend from involved devices radio's transmitting power, receivers' sensitivity, and antenna type and tuning as well as from obstacles between devices and a number of devices on the same LAN.

Communication distance increase for lower carrier frequencies 433 MHz and 868 MHz, compared to 2,4 GHz, 5 GHz or higher frequencies.

Special and important communication between all wireless communication methods are cell networks and data transmission over them. These networks today offer wide network coverage, fast data exchange, security, etc.

B. Sensors

For the same physical phenomena data acquisition are available several devices and methods.

Important point is sensor data output: analogue, digital or communication (UART, I2C, SPI or other).

All sensors can be divided in 3 large main groups:

- 1) Event detectors: burglar alarms, fire and smoke detectors, PIR presence sensors, for example. The most important are reliability: sensor must act as planned when triggering conditions take place. For example, airbag activation sensor in vehicle safety system.
- 2) Metering sensors: electrical power consumption meters or soil pH meters, for example. Relation between maximum and minimum values can be in range from 10 to 100 times and more. Thus, sensors can have built in automatic ranging system or range must be chosen remotely. Metering sensors must have persistent characteristics (calibration, for example) for significant

time period under outside weather and other conditions (vandal resistant, for example).

- 3) Image or video capturing cameras. Mainly are used for better understanding or explanation of other sensor readings or physical damage detection via observation (long distance high voltage power transmission lines, for example).

Metering sensors can act as:

- "pure" metering device,
- Selective metering or triggering device, generally based on logical functions *if* and *then*:

- *if (value) > threshold, then (action),*
- *if (value) < threshold, then (action),*
- *threshold_low < if (value) < threshold_high, then action.*

- Monitoring device (precision in range 2, 5 - 5%) for information visualization (like LED graph bar) or measured value are just a kind of "to know".

C. Sensor Power Supply

Sensor can be powered in various ways:

- 1) household or industrial AC mains through power supply module,
- 2) battery,
- 3) small solar panels,
- 4) tiny wind turbines,
- 5) wirelessly over air,
- 6) via energy harvesting from electromagnetic waves (radio stations, mobile networks),
- 7) via energy harvesting from electrostatic field (fluorescent lamps / compact fluorescent lamps),
- 8) via energy harvesting from vibrations,
- 9) Thermoelectric effect electric generators and other.

Power supply versions from 3) till 9) require additional energy storage device and typically rechargeable battery (accumulator) are applied, but super capacitor energy storage become more and more popular as battery replacement.

Both require special charging circuit to achieve planned

lifetime, capacity and discharging characteristics.

Long-life battery is one of the most expensive system components so selection must be very precise according to sensor and system task.

D. Data Processing, Representation and Storage

Frequently sensor data processing first step are provided on site by low energy consumption micro-controller, if necessary.

Following data processing, storage and representation are done by means of ICT. Here several main tendencies can be recognized:

- 1) special computer software installation on personal computer,
- 2) using third party offered computing capacities and data storage,
- 3) internet based,
- 4) mixed.

Computer or local data server can run on any of the operating systems (OS) developed until now:

- UNIX,
- kind of POSIX (UNIX-like) operating systems,
- Linux,GNU,
- BSD and its descendants (FreeBSD, OpenBSD, NetBSD),
- Apple OS X,
- Google Chromium,
- Microsoft Windows.

Portable and mobile devices run:

- IOS (Apple products),
- Android (main promoter - Google),
- Symbian (Nokia).

Mostly Apple OS X, Microsoft Windows, Linux, iOS and Android are in use, as known.

Wide variety of devices and operating systems and need for mobile access to data and commands set internet browsers (more precisely - browser software) as the main data representation and command tool today. All popular browsers like Safari, Firefox, Chrome, Explorer can display coded in HTML5 content.

HTML5 is cross-platform software - to work with a PC, Tablet or a Smartphone and was designed to deliver rich content without the need for additional plugins.

HTML5 delivers everything from animation to graphics, music to movies, and can also be used to build complicated web applications, including sensor data representation.

Internet browser is "just a tool", for remote sensing systems, in context of this article.

Other programming software (and hardware) allow to store sensor readings and data, process requests and send necessary information as HTML5 code to web browser.

Typical software set widely applied today:

- user side:
 - internet browser,
- server side:
 - Apache web-server,
 - hypertext preprocessor PHP,
 - MySQL database.

Such set also can be applied for mentioned in this article tasks.

Described below systems on server side use Apple OS X, and FileMaker Pro database software. FileMaker Pro

software offer easy implementation, integrated web-server and special FileMaker network for easy data transfer.

III. DEVELOPED REMOTE SENSING - CONTROL APPLICATIONS

Many available remote sensing techniques and tools, as well as communication tools are available today and some of them are implemented and tested during several projects:

- e-Learning Workshop,
- LED street illumination,
- Electrical energy consumption monitoring,
- Pedestrians' visibility active beacon.

A. E-Learning Workshop

E-Learning workshop was designed to improve education in the field of computer control of electrical technology [5].

Students are able to perform simple and typical laboratory tests through internet.

Workshop communication structure diagram are shown on Fig. 2.

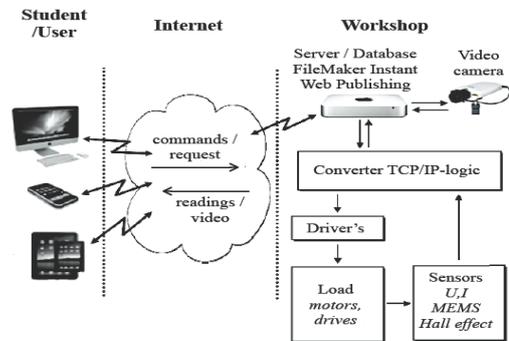


Fig. 2. E-Learning workshop structure.

All control actions are preformed, results are displayed and devices are observed in computer, tablet or smartphone internet browser. Smartphone screen are too small for good observation, so amount and kind of reflected information on the screen must be carefully weighted on system design stage.

System response time is very important here - User doesn't accept long time delay between sending a command and device action, observed by means of video camera.

Response time include:

- Internet delay time, depending from many factors and cannot be shorten,
- Local e-learning workshop wireless communication delay time. Local delay can be reduced by proper communication time selection depending from communication method.

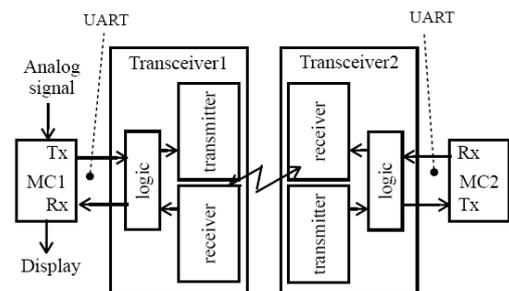


Fig. 3. Wireless communication response time testing block diagram.

Several wireless communication devices and protocols were tested according to the block diagram shown on Fig. 3. Method measure “send-receive-send” time or “echo” time.

Test results are displayed on Table I.

TABLE I: SEND - RECEIVE - RE-SEND TIME (ECHO TIME) TEST RESULTS

Communication	Bitrate, Kbit/s	Send-receive-re-send time, ms	Distance
UART protocol, AM transmitter and receiver, 433 MHz, 7 data bytes	<1,2	67-68	<6 m
UART protocol, FM transmitter and receiver, 868 MHz, 7 data bytes	<1,2	67-68	<15 m
UART ports FM transceiver 433 MHz, 7 data bytes	9,6	80-82	~250 m
ZigBee protocol data exchange 868 MHz, 7 data bytes	9,6	155-160	~200 m
ZigBee protocol data exchange 868 MHz, 64 data bytes	9,6	252-258	~200 m
ZR7AZ/ZF-1 transmitter / receiver 433 MHz	31,25	300-340	<100 m

On project pilot stage sensors have cable communication. After testing wires was replaced by Hope-TRP transceiver based wireless links, according to test results. Communication protocol here is well known UART and transfer rate is 9600 bit/s.

The main disadvantage for Hope-TRP application is: security or devices pairing must be included in to micro-controller generated UART code. In this case security relay on programmer's knowledge about ICT security methods and from micro-controller performance - ability to include security in to code without significant reduction of speed.

This communication method can be applied for simple data transfer when security isn't a priority and wrong data from outside cannot trigger any damage by turning ON or starting electro-technical device.

WiFi wasn't tested because the target was switch to ZigBee/XBee communication.

ZigBee/XBee testing results:

- high security,
- complexity during installation,
- need special software X-CTU for Digi International ZigBee/XBee modules code writing and upload,
- low transmission speed: effective data transfer speed is about 0,4 [6], thus, lower energy efficiency,
- necessity to keep network Coordinator always ON - low energy efficiency,
- 868 MHz carrier system was more stable than 2,4 GHz carrier system. Probably due to several WiFi LAN's in the same area.
- communication timeout was recorded,
- long send-receive-send time,

ZigBee/XBee testing results was more negative, than positive and result as disappointment about ZigBee/XBee.

B. LED Street Illumination

LED street illumination control and information acquisition about luminaries power consumption, reflected illumination, outdoor temperature, passed traffic count, etc., was developed during several projects, for example [7].

Smart illumination control still is under development.

Different communication modules/systems were tested during development:

- 1) UART - Hope TRP,
- 2) ZigBee/XBee,
- 3) WiFi,
- 4) WiFi + 3G/4G.

Below are described the main results and suggestions.

UART - Hope TRP implementation results:

- Very easy implementation,
- Stable process,
- 433 MHz require a bit to long antenna - 173 mm,
- ~250-300 m communication distance without flexible antenna ground plane at 25-26 mW (14 dBm, according to data sheet) transmitter output power,
- ~400 - 450 m communication distance with flexible antenna and ground plane at 25-26 mW transmitter output power,
- Easy wakeup from sleep state to active state.
- Complicated linking to Internet - need separate module,
- Security need to be stronger,
- ~ 60-65 mW power consumption during receiving state is a bit to high but acceptable here.

ZigBee/XBee implementation results (433 MHz and 2,4 GHz carrier frequencies) are the same as described above in e-Learning workshop results,

WiFi implementation results:

- Microchip MRF24, H&D Wireless HDG104 based modules was tested,
- Non-complicated setup,
- Perform typical WiFi characteristics,
- High security,
- Necessity to place WiFi LAN Name and Password in to micro-controller code - problematic to change WiFi LAN,
- Problematic to cover larger area.
- Delays due to several WiFi LAN's in the same area or if the same router also serve other computer, mobiles, tablets, etc.

WiFi + 3G/4G implementation results:

- Electric imp [8] or simply *IMP* modules wirelessly connected to Huawei 3G/WiFi router E5151 (8 WiFi addresses) or Huawei E5172 (32 WiFi addresses) are applied,
- Easy setup,
- Perform typical WiFi characteristics,
- Easy micro-controller code change (code upload through internet),
- Easy to change WiFi LAN Name and Password, if necessary,
- Low power consumption,
- Integrated and tuned antenna,

Below are more detailed *IMP*-based system descriptions.

C. Electric Energy Consumption Monitoring

Electrical energy consumption monitoring allow to save energy by pointing to ineffective energy usage or simply energy wasting. Saving is important now and will be more important in future, so many systems are on the market today - smart and not so smart.

Currently about saving take care only big and large scale manufacturers - automotive, leading ICT companies.

Households are different. Developed projects and provided

tests [9]-[11] allow to conclude: current low energy price doesn't create wide consumer interest about energy consumption saving (and monitoring) - to expensive, 3-5 years payback time for average monitoring system, lack of knowledge about electricity and electricity units. Until you aren't "green".

Question "does the TCO is worth for acquired data importance?" is important to this field.

The latest designs are based on new consumed energy sensing method [12], corresponding module and electric imp to develop "tool for rent".

D. Electric Imp Platform (IMP)

IMP developer: "The Electric Imp connectivity platform, featuring fully integrated hardware, software, OS, APIs,

cloud servers, makes it possible to effectively empower devices with intelligence, scalability and flexibility."

Author's experience with IMP implementation and application reflect ease of use and short project setup time, compared to other micro-controller + WiFi solutions,

For example, it is difficult to develop, realize and tune system including 97 DC motor's bi-directional semi-synchronous control and corresponding MEMS 3-axis accelerometer data acquisition system during 3 weeks period. Especially if devices are spread over 150 x 24 m area in vertical plane. IMP was very handy for this task. Control and data storage was based on FileMaker Pro database software [13].

IMP WiFi + 4G application block diagram is shown on Fig. 4.

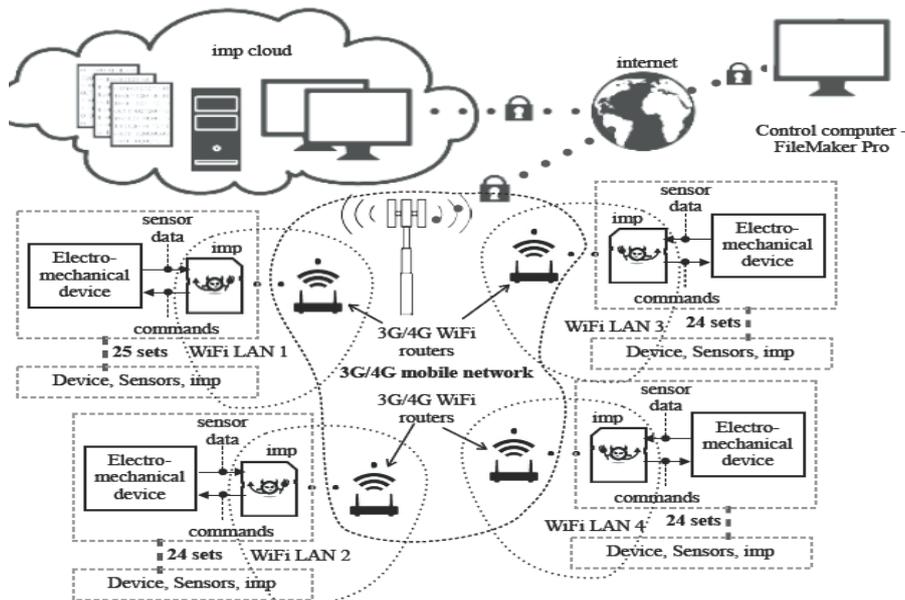


Fig. 4. IMP WiFi + 4G application block diagram.

SD card size IMP module include 32-bit Cortex micro-controller and WiFi radio with integrated, tuned antenna. Lightweight application software code are written in Squirrel language (C-like) and uploaded through secure internet connection.

E. Pedestrians Visibility Active Beacon

Another imp implementation was pedestrians' visibility active beacon.

European research found that one-third of pedestrian casualties had difficulty seeing the vehicle that had struck them, while two-fifths of drivers had difficulty seeing the pedestrian.

It is known that driver must recognize pedestrian as minimum 100 meters in advance for driving speed 90 km/h (Fig. 5).

These are well known facts and special measures must be taken to increase pedestrian visibility on the road: reflective jackets, reflective add-ons or individual active beacon.

Active beacon consists of pedestrian front and back light sensors, front and back LED's, all pointed to possibly approaching vehicle, IMP module and battery.

Operation is simple: LED begins flashing if illumination level is higher, compared to previous value: car is approaching with headlights ON and distance between pedestrian and vehicle continuously decrease. LED stop flashing when illumination are stable or come lower - vehicle was passed.

Active beacon are powered by 2 AA batteries or 3, 6 V LiPO battery and based on IMP due to low power consumption (~ 9-10 mW) when WiFi are turned OFF.

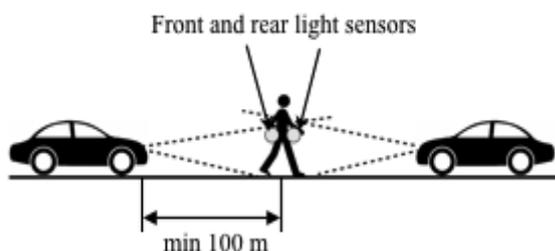


Fig. 5. Front and rear light sensor and pedestrian-car position on the road.

IV. CONCLUSION

From rapid and adequate sensor's network development point of view there are two technologies on the market today - electricimp module and UART radio link modules.

Ongoing work will be provided with electricimp implementation due to constantly growing platform possibilities.

Bluetooth Low Energy modules must be tested to find out

implementation questions and ease of data remote acquisition, as well as from service point of view.

More attention must be turned to mobile devices.

Possible server hardware and software reduction or only cloud data storage must be tested.

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During 45 years of practical, scientific research and R&D experience in fields of electronics, power electronics, industrial automatics, ICT, printing & publishing and paper-making he listed more than 330 designs and implementations of the devices and projects. He has published more than 30 publications and has 3 patents. Currently he works as a leading researcher and assistant professor at Institute of Industrial Electronics and Electrical engineering, Riga Technical university, Latvia.