RIGA TECHNICAL UNIVERSITY
Faculty of Power and Electrical Engineering
Institute of Industrial Electronics and electrical Engineering

Peteris APSE-APSITIS
Doctoral program „Computer control of electro technologies” PhD

RESEARCH OF THE WIRELESS MONITORING AND CONTROL SYSTEMS FOR ELECTRO-TECHNOLOGICAL DEVICES

Summary of the Doctoral Thesis

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CONFIRMATION

I hereby declare that I have worked out this Doctoral Thesis, which has been submitted for review at Riga Technical University for the award of a doctoral degree in the field of engineering. This Doctoral Thesis has not been submitted to any other university for the award of a scientific degree.

Peteris Apse-Apsitis …………………………….(Signature)

Date: ………………………

The thesis is written in Latvian, contains an introduction, four chapters, conclusions, 10 attachments, 91 figures, 8 tables, 153 pages, 134 sources of information.

GENERAL DESCRIPTION OF THE THESIS

RELEVANCE OF THE THESIS

For the last 10-15 years the ICT in general and the wireless communication in particular have become a major topic of economic and industrial research. The development of wireless data communication is mainly driven by the increasing use of multifunctional stationary and mobile devices and the growing necessity of wireless communication among these devices.

Partially autonomous electro-technological devices (ED) are increasingly integrated into larger systems, therefore devices and modules for centralized control, data storage, etc., are necessary. In many cases, e.g., when EDs are located in separate buildings or when the layout of the EDs (mobile devices or nodes) is modified, it may be difficult or even impossible to use wired communication.

One possible solution is wireless communication (Wi), however the possibilities of its application in wireless monitoring and control systems for electro-technological devices (WMCSED) are not clear (Fig. 1).

For several decades the author has followed scientific literature, articles and white papers on the subject, and it can be concluded that the wireless communication is mostly described from the angle of software, applications or practical implementation, and that the scientific literature related to the use of wireless communication in WMCSED is limited and fragmented.

It is not clear what are the possibilities and complexities for using affordable wireless communication solutions (ZigBee or SRD) for WMCSEDs.

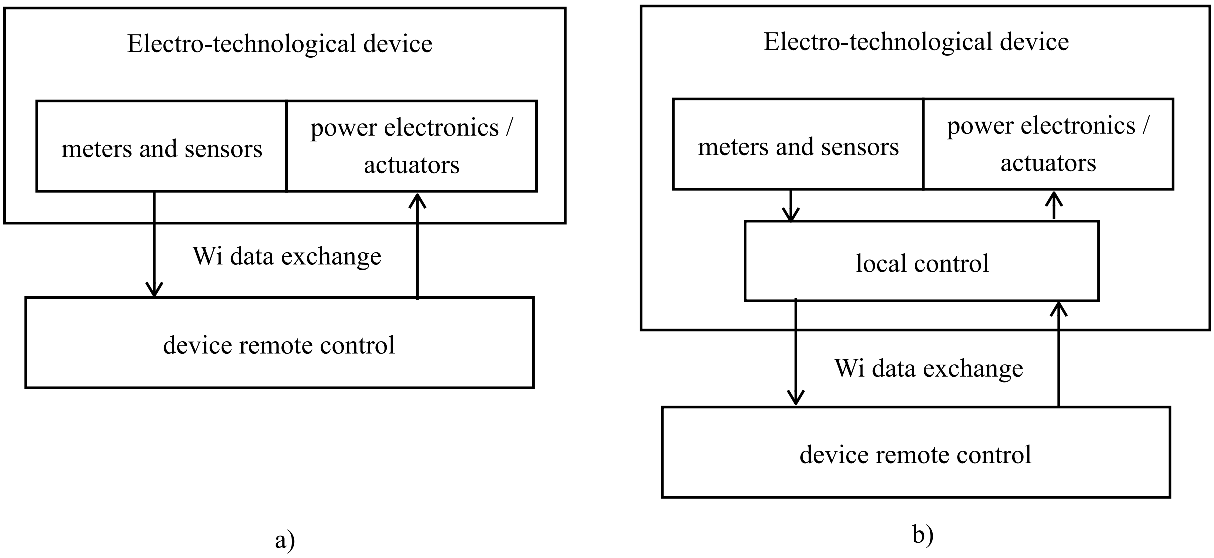


Fig.1.Direct (instantaneous) a) and real-time b) WMCSED

AIM OF THE RESEARCH

The aim of the research is to investigate the suitability of known and affordable wireless data sharing solutions for dispersed or modular (cloud) electro-technical devices and for direct or real-time obtainment of parameter values, and to experimentally verify these solutions in the context of WMCSEDs.

SCIENTIFIC NOVELTY OF THE RESEARCH

The scientific novelty lies in:

- the classification of WMCSED,
- the claim that a direct (transparent) WMCSED can be implemented by an analog (AM / FM) or digital (ASK / FSK) radio carrier wave modulation that uses an analog parameter value or a proportional pulse length as a modulating signal, but cannot be implemented by serial communication protocols,
- the claim that a real-time WMCSED can be implemented by using the UART data exchange protocol, but is difficult or impossible to implement with the IEEE 802.15.4 standard protocol used by ZigBee.

PRACTICAL VALUE OF THE RESEARCH

The practical value of the research lies in the developed for experimental purposes devices:

- dimmers for LED lamps, WMCSED controls with a relational database and corresponding micro-controller program codes are used in the realization of the project "Development of a prototype of a LED based street lighting system with an intelligent lighting control", co-financed by the Climate Change Financial Instrument of the Ministry of Environmental Protection,
- prototype devices used in practical electro-technical training within electrical engineering studies have been developed and tested,
- electric drive for a snake-like robot and a temperature-compensated shunt for current measurement are patentable.

STATEMENTS SUBMITTED FOR DEFENSE

1. The claim that communication wires of an ED cannot be directly replaced by a WMCSED due to time delays, except in specific cases.
2. The claim that a WMCSED mainly can carry out general monitoring of the ED parameters and provide general ED control.
3. The new electrical energy consumption monitoring method and apparatus for the group of the individual energy consuming devices.
4. The new energy saving method and apparatus for robotic arm control an integration in to WMCSED.

STRUCTURE OF THE THESIS

The Summary of the Thesis consists of an introduction, four chapters, conclusions and bibliography.

The Thesis comprises 153 pages, 90 images, 8 tables, 10 appendices, 134 information sources.

APPROBATION AND PUBLICATIONS.

The scientific results have been reported and discussed at the following international conferences:

1. Annual 17th International Scientific Conference “Research for Rural Development 2011” Proceedings, (Volume 1), LLU, Jelgava, Latvia, 2011, report “Low Cost Energy Monitoring Method with Wireless ICT”,
2. 53rd International Symposium ELMAR 2011, Zadar, Croatia, 2011, report “Concept of Low-Cost Energy Monitoring System for household Application”,
3. 2nd IEEE ENERGYCON Conference & Exhibition, 2012 - ICT for Energy, Florence, Italy, 2012, report “Wirelessly controlled LED lighting system”,
4. 3rd IFIP WG 5.5/SOSOLNET Doctoral Conference on Computing, Electrical and Industrial Systems, DoCEIS 2012, Costa de Caparica, Portugal, 2012, report “Development of Energy Monitoring System for Smart Grid Application”.
5. 16th International Conference ELECTRONICS 2012, Palanga, Lithuania, 2012, report “Self-tuning CORE-less serial Resonant DC/DC Converter for Powering Loads on Rotating Shafts”,
6. 10th International Symposium “Topical Problems in the Field of Electrical and Power Engineering, Pärnu, 2011, report “CANbus elements in robotic snake-like movement device control”,
7. 15th International Conference “Interactive Collaborative Learning” ICL 2012, Villach, Austria, 2012, report “Remote Workshop for Practical Knowledge Improvement in Electrical Engineering Education”,
8. 52nd Annual International Scientific Conference of RTU, Riga, Latvia, 2011, report “Household Energy Consumption Monitoring”,
9. 52nd Annual International Scientific Conference of RTU, Riga, Latvia, 2011, report “Embedded ICT for Railway Safety”.

The main results are described in 16 publications (see pages 23-24)

THESIS CONTENTS

INTRODUCTION

It is difficult or sometimes even impossible to use wired communication among mobile electro-technical devices or electro-technical devices located in different buildings. One possible solution is wireless communication, however the possibilities of its use in the context of WMCSEDs so far have not been properly described. This research is focused on these options.

CHAPTER 1. THE FUNCTIONAL STRUCTURE AND CLASSIFICATION OF WMCSED

In terms of functionality a WMCSED consists of two main units: an ED parameter measurement / command implementation unit and a remote control unit, both of which are equipped with wireless communication modules. Wireless communication can be simplex (one-directional) or duplex (two-directional). Duplex communication are divided in to half-duplex or full-duplex systems.

Half-duplex systems are the most widely used since they offer simpler and cheaper technical solutions - systems use a single carrier frequency and transmission and reception takes place alternatively.

WMCSEDs have different functions and designs, and several WMCSED classifications are possible (Fig. 2.):

a) by dialog mode, b) by carrier, c) by coverage.

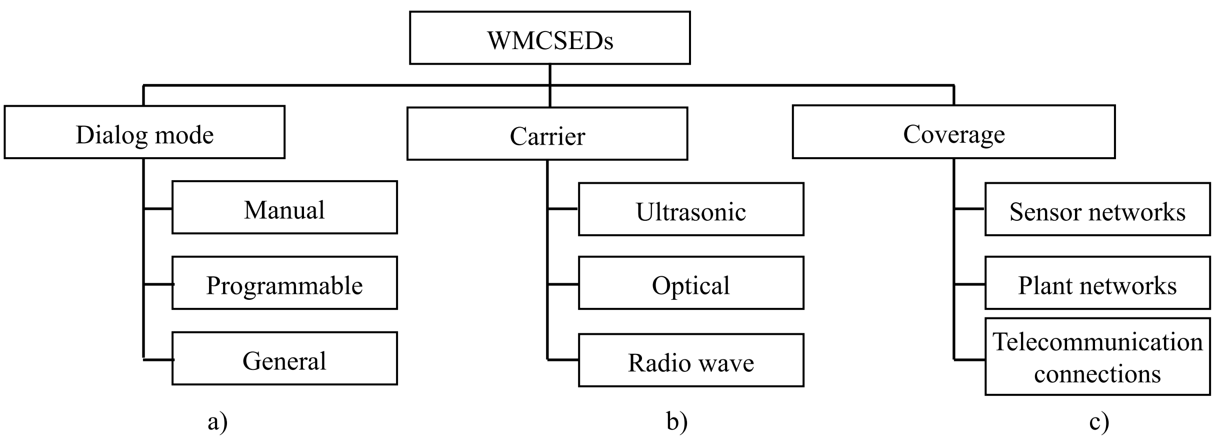


Fig.2. Classification of WMCSEDs: a) by dialog mode b) by meduim c) by coverage

WMCSEDs mainly use a radio carrier wave and defined communication protocol. WMCSEDs can be classified by communication protocols can be grouped according to certain standards (Fig. 3).

Classification by response time

Depending on the type of the wireless communication and on the connection among ED nodes, WMCSEDs can be divided into:

- direct WMCSEDs,
- real-time WMCSEDs,
- general WMCSEDs.

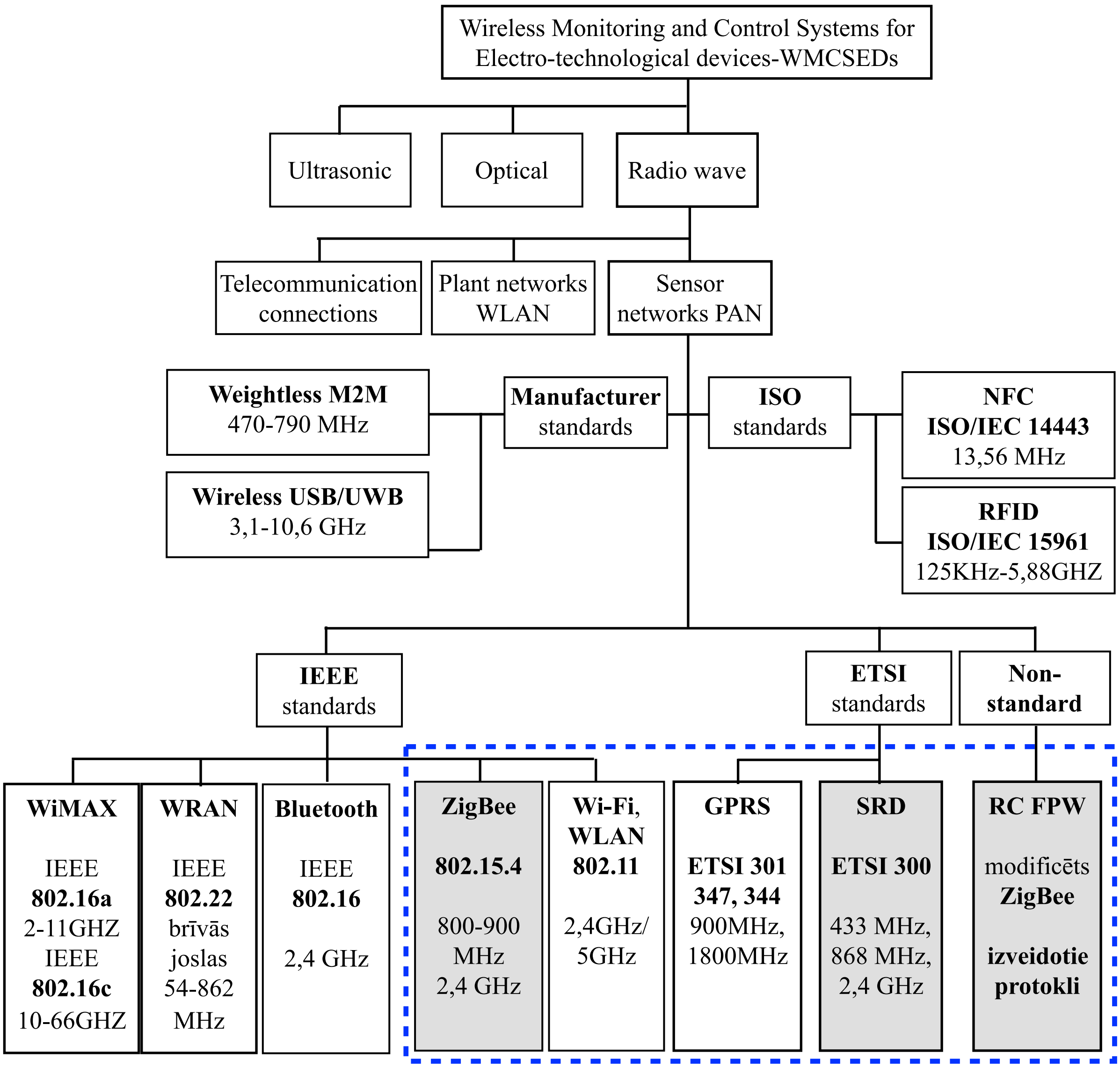


Fig.3. WMCSED classification by carrier, network, standard and communication protocol

The classification by response time is very significant in further WMCSED research, development and deployment.

CHAPTER 2. WMCSED METHODOLOGY - ANALYSIS AND SOLUTIONS

The function of a WMCSED is remote monitoring of ED parameters and remote management of these devices, replacing the wired communication by a wireless communication channel.

In terms of WMCSEDs a wireless communication unit is considered to be a space-dispersed connecting element substituting the wired communication, of power electronics and control units of the electro-technological device (Fig. 1).

The total time of the measurement – command cycle is made up by the following elements and are calculated as:

$$T_C = T_M + T_{SA} + t_R + t_{SU} + t_{IE} \quad (1)$$

where T_C - total cycle time

t_M - the measurement acquisition time,

t_{SA} - reception time through a wireless link,

t_R - response time of the control unit,

t_{SU} - sending time through a wireless link,

t_{IE} - response time of the power electronic device.

Wireless communication should be considered a variable time delay element introduced in the electro-technological equipment (system).

Radio wave carrier modulation for information transmission.

Radio wave carrier modulation associated with the parameter reading values of the electro-technological device can be either continuous or discrete (digital).

Today digital frequency modulation or phase modulation is mostly used. Amplitude modulation has a lower interference resistance, moreover, the amplitude modulated signal spectrum contains the carrier frequency, as well as the upper and lower side frequencies, which significantly reduces energy efficiency of the amplitude modulated carrier. It is possible to increase the efficiency by means of a single sideband modulation (SSB).

In the context of WMCSEDs the main advantage of the analog modulated radio signal is the capability to receive measurements of several parameters or to send multiple commands. When transmitting individual measured parameter values, low frequency Ω1, Ω2, Ω3 amplitudes are modulated and aggregated in a single signal which modulates and transmits the carrier frequency (Fig. 4). The sum of the voltages U1, U2….UN characterizing individual parameter values shall not exceed the total acceptable value of modulation voltage and carrier voltage.

The primary disadvantage of analog modulation is the limited dynamic range of the parameters (sum of U1, U2….UN) to be transmitted.

The dynamic range of an analog modulated signal is less than 48 dB and in practice it does not exceed the 8-bit ADC dynamic range of 48.17 dB, calculated as:

$$DR_{ACP} = 6{,}0206 \times n = 6{,}0206 \times 8 = 48{,}165(dB) \quad (2)$$

Dynamic range of 10-bit ADC widely used in micro-controllers 60,2 dB.

A shortcoming of an analog modulated carrier is its low interference resistance to a variety of sparking processes, e.g., in electric brushes, which limits the possibilities of its application in WMCSEDs.

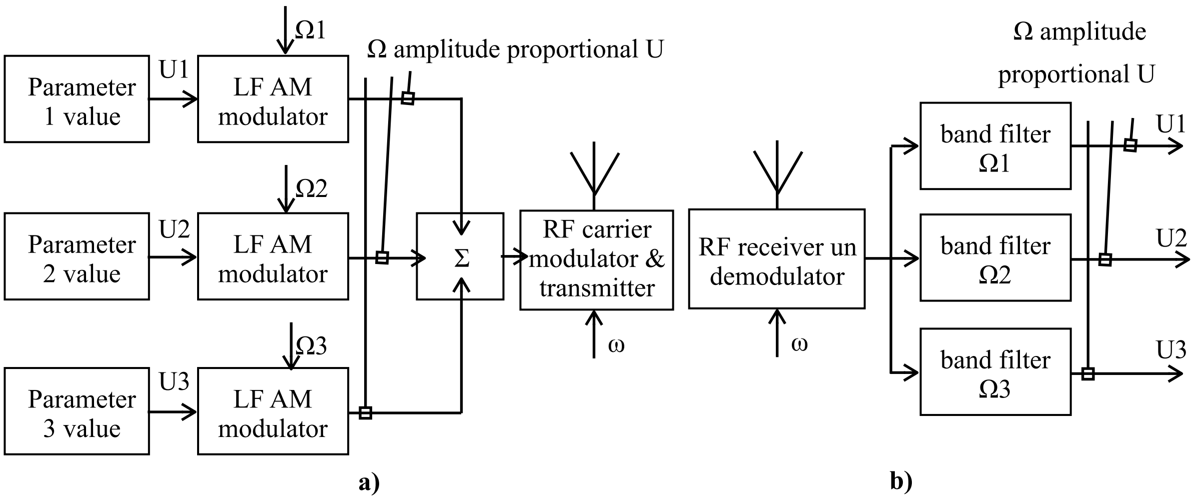


Fig.4. Block diagram of a analog modulated carrier based WMCSED
a) transmitter, b) receiver

In order to minimize the influence of radio interference, the analog value of the measured parameter can be converted into a pulse of proportional length. When transmitting, 100% modulation is used, which is equivalent to a switch position "on-off" (Fig. 5).

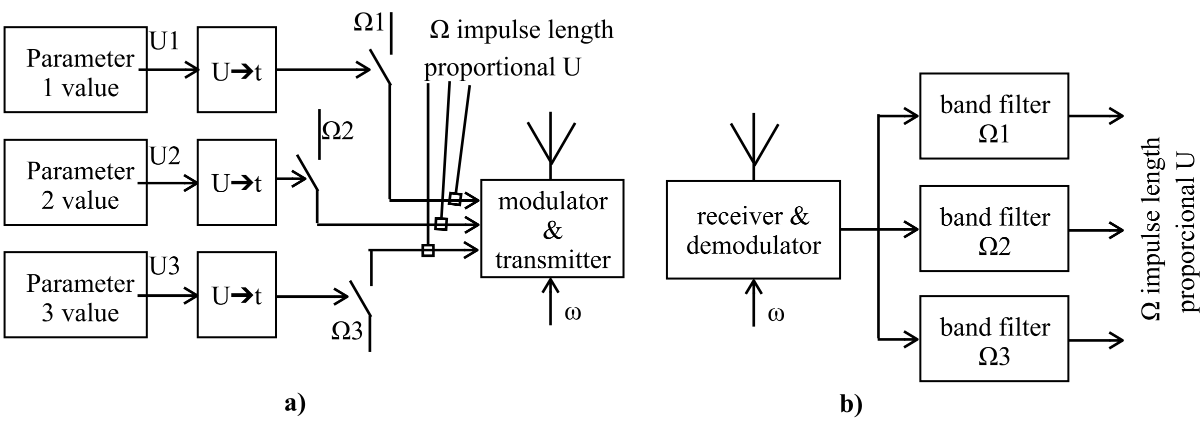


Fig.5. Real time WMCSED block diagram converting parameter value to proportional impulse length
a) transmitter, b) receiver

DTMF (dual-tone multi-frequency signaling) increases the reliability of WMCSEDs. DTMF uses a 4x4 matrix of frequencies (Table 1) which are selected to minimize the chance of accidental formation. DTMF frequency combinations are transmitted sequentially, parameter by parameter, command by command. When a WMCSED uses DTMF, it becomes more like a real time WMCSED and cannot be considered direct anymore.

DTMF FREQUENCY MATRIX

Table 1

	1209 Hz	1336 Hz	1477 Hz	1633 Hz
697 Hz	1	2	3	A
770 Hz	4	5	6	B
852 Hz	7	8	9	C
941 Hz	*	0	#	D

Direct WMCSEDs

A direct WMCSED is a WMCSED that does not alter the functioning of an ED by substituting wired communication with a full duplex radio link.

Simultaneous transmission of multiple parameters or commands can take place as shown in Fig. 7 and Fig. 8. Thus the use of an individual carrier frequency for each parameter can be avoided.

Radio wave (ZigBee, SRD etc.) low-speed serial data exchange communication is not suitable for direct management of EDs, as it can significantly modify its functioning due to introduced time delays.

Real-time WMCSEDs

A real-time WMCSED is a WMCSED that does not fundamentally alter the functioning of an ED by replacing the communication wires between the ED and its remote control with a radio link (Fig. 6).

The total command sending and data receiving time of real-time WMCSEDs does not exceed the human response time (160-180 ms in average)

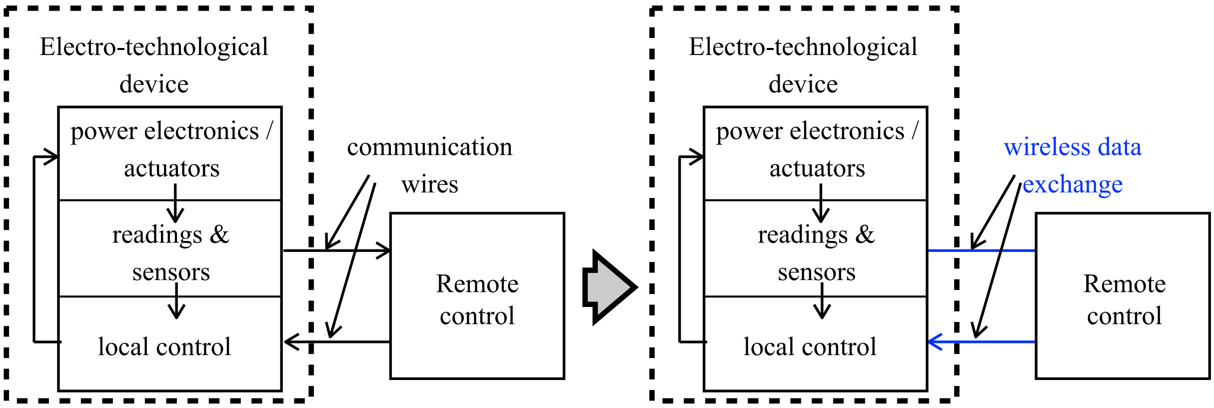


Fig.6. Real time EEWMCS

Universal WMCSEDs

Technical solutions for universal WMCSEDs are no different from those for the direct or real-time WMCSEDs.

The difference from the real-time WMCSEDs lies in the total command sending and data receiving time which exceeds the human response time in manually controlled systems (160-180 ms in average).

Universal WMCSEDs are used for simple tasks where the response time is not critical to correct functioning of the equipment.

WMCSED networks

WMCSED networks may experience time delays that exceed the time criterion of command sending and data receiving (160-180 ms) of real time WMCSED.

WMCSEDs mostly use star network, because the design dimensions of an ED do not exceed the operating range of the transmitter-receiver and transceiver of 100-1000 m. Star network do not use data or command relays.

WMCSED network with a relational database control

The described WMCSED methods and solutions have the following drawbacks:

- lack of visualization
- communication loads of WMCSED modules when operating in a network are not taken into account,
- lack of an intuitive and user friendly interface that can be easily customized according to user needs,
- requires a good knowledge in micro-controller and module programming.

Databases allow for automation of many repetitive tasks, e.g. WMCSED tasks. Therefore it is appropriate to manage WMCSEDs using a database program. The author defines a database as follows:

A database is method / means for organization and analysis of information.

Using the software "FileMaker Pro" even non-professional users can create and modify a user friendly database and perform a variety of calculations. "FileMaker" is a relational database which offers a range of possibilities to create a user interface that allows for an intuitive and user friendly WMCSED management.

According to the information available “FileMaker” so far has not been employed in WMCSED solutions.

Determination of information send-receive time

A block diagram for determination of information send-receive time is shown in Fig. 7. Information is sent from MC1 by a transceiver R1, received by a transceiver R2, decrypted by MC2 and sent back to MC1 by the transceivers R1 and R2. This process is also referred to as an "echo". The experimental results are reflected in the Table 2.

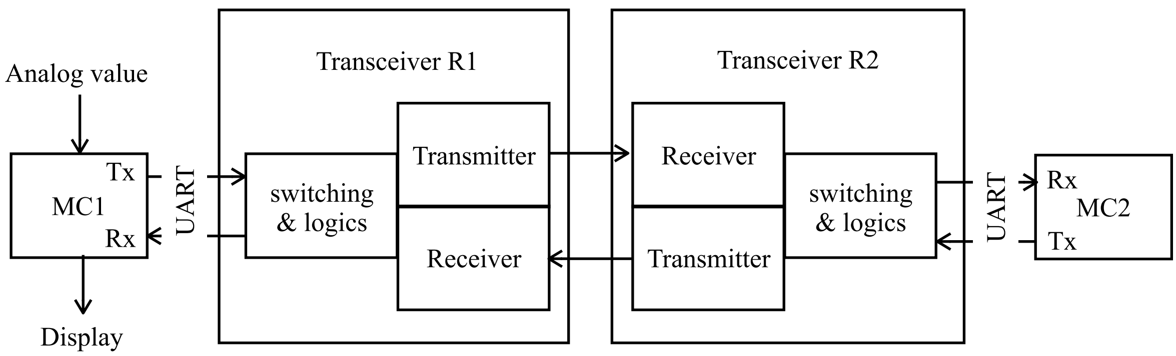


Fig.7. Send-receive time testing block diagram

This "echo" process includes all the information and data bytes of the chosen communication protocol.

The send-receive time should be determined by the "echo" method in real environment, e.g., in a plant, before the WMCSED is designed and implemented.

SEND - RECEIVE TIME TEST RESULTS

Table 2

Communication	send-receive time, ms	Remarks
two RC servos direct control FM transmitter HM-T, receiver HM-R, 868 MHz	<0,1	distance <25 m frequency coding
UART protocol, simple AM transmitter-receiver, 433 MHz, 7 data bytes, max 1200 bit/s	67-68	distance <6 m
UART protocol, simple FM transmitter-receiver, 868 MHz, 7 data bytes, max 1200 bit/s	67-68	distance <15 m
UART ports FM transceiver 433 MHz, 7 data bytes, 9600 bit/s	80-82	distance ~250 m
ZigBee protocol data exchange 868 MHz, 7 data bytes, 9600 bit/s	155- 160	distance ~200 m
ZigBee protocol data exchange 868 MHz, 64 data bytes, 9600 bit/s	252- 258	distance ~200 m
ZR7AZ/ZF-1 AM transmitter / receiver 433 MHz, 31,25 Kbit/s	300- 340	distance <100 m

The "echo"method is the only reliable method for the send-receive time determination, as it takes into account all the information and data bytes, as well as the influence of environmental interferences on the communication process.

CHAPTER 3. DEVELOPMENT OF NEW WMCSED BASED UNITS

3.1 Snake-like movement device

A proprietary snake-like movement device (Fig. 8) can be employed either as a robotic / manipulator arm or as a separate unit. The snake-like movement occurs relative to the end of the modular chain that is affixed to the body.

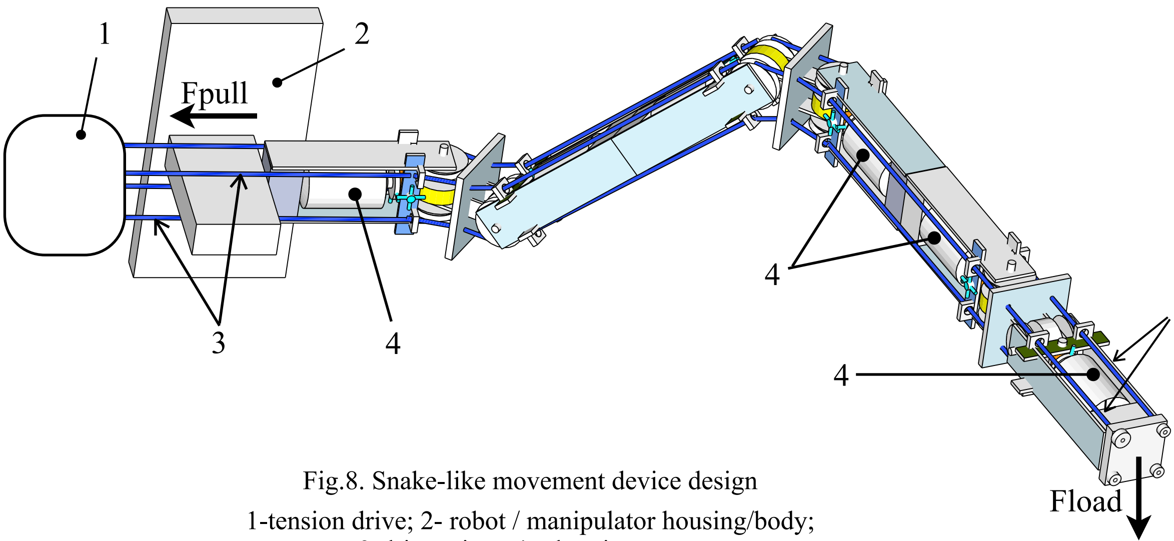


Fig.8. Snake-like movement device design

1-tension drive; 2- robot / manipulator housing/body; 3-drive wires; 4- electric motors

The modular parts P1 and P2 change their position in relation to each other as a result of tension in the drive wires (forces F1 and F2) if the electric motors 4 (M1, M2) that are turning the worms 3 allow to turn the worm-gear 2 (Fig. 9).

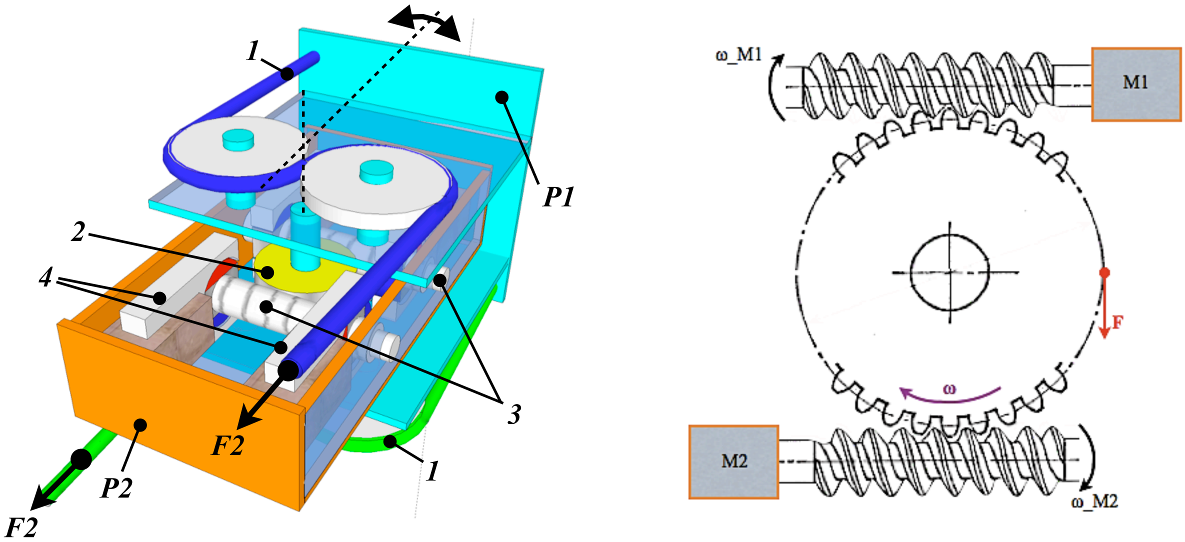


Fig.9. Device module
P1, P2 - modular parts, 1) drive wires 2)-wormgear 3) - worms 4) - stepping motors

The drive wires provide power supply, while the operation of the electric motors is controlled from a central module by wireless data transmission. In a similar way the information about the position of each module is received from inclination sensors.

MODULE ROTATION ANGLE ERROR DUE TO WMCSED TIME DELAY

2.3. tabula

ω, deg/s	n, apgr/min	ω, deg/ms	α_{eho}, deg (T_{eho} =82 ms)
15	2,5	0,015	1,23
30	5	0,03	2,46
60	10	0,06	4,92
90	15	0,09	7,38

The design of the snake-like movement device allows to change the profile of the module chain by changing the tension in the drive wires and simultaneously the operation of the electric motors. No brakes are required for profile retention: this is an energy efficient solution.

3.2. Temperature-compensated shunt for current measurement and integration into WMCSEDs

A communal electricity metering system does not allow to determine the electricity consumption of an individual electricity consuming device due to metering at a single point (Fig. 10)

It is possible to identify the individual consumption by monitoring either the distribution of currents among several electricity consuming devices (4) or the electrical resistance of the electricity consuming devices (5).

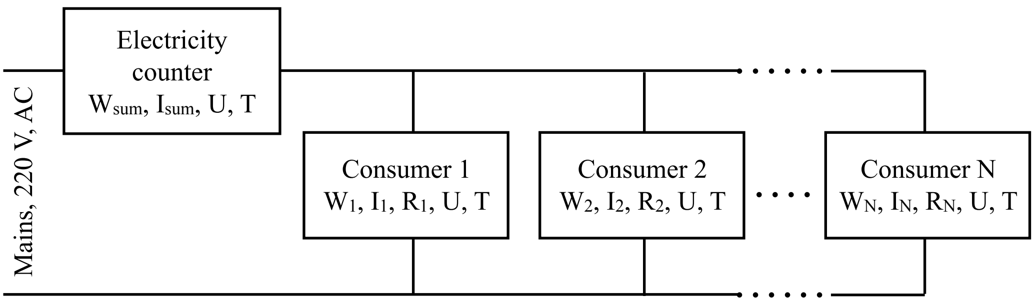


Fig.10. The electricity consumption metering of a set of electricity consuming devices

Energy consumption can be calculated by equitation:

$$W = P \times T = I \times U \times T = \frac{U^2}{R} \times T, \quad (3)$$

where W - electricity, Wh,

P - power of the electricity consuming device, W,

T - duration of power P consumption, h,

I - current of the electricity consuming device, A,

U - voltage of the electricity consuming device, V,

R - active resistance of the electricity consuming device, Ω.

Voltage and time parameters are identical for all the electricity consuming devices. Therefore the ratio of the energy consumption of each device to the total energy consumption is determined by the distribution of currents:

$$I1/Isum + I2/Isum + \ldots + IN/Isum = 1, \quad (4)$$

where I1, I2, ..., IN - the current of each electricity consuming device,

Isum- total current in the electricity meter.

The current of each electricity consuming device is determined by its active resistance or complex impedance. Therefore the distribution of the consumed power is determined by the resistances of the power consuming devices:

$$1/R1 + 1/R2 + \ldots 1/RN = 1/Rsum, \quad (5)$$

where R1, R2, ..., IN - each active resistance,

Rsum- the total resistance connected to the electricity meter

The resistance of each electricity consuming device is measured by a sensor of specific design (Fig. 12), a low-cost precision resistor R6 and an electrical circuit (Fig.11).

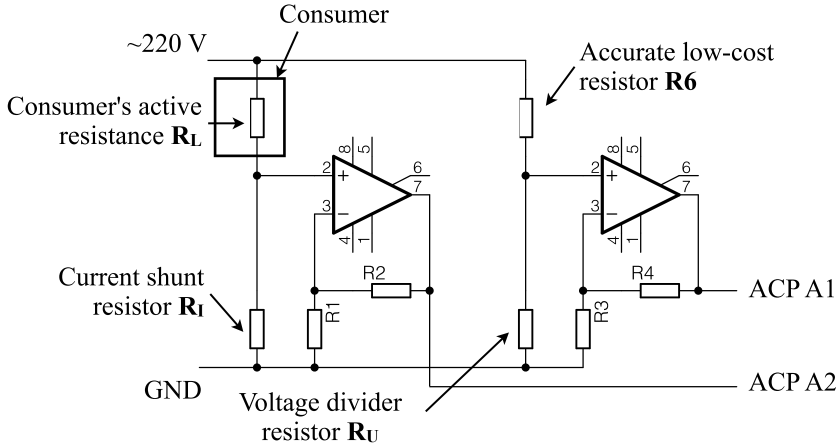


Fig.11. Measuring circuit

The sensor consists of an electronic printed circuit board ***6*** (Fig. 15) that includes a current sensing resistor (shunt) ***3*** in a form of a trace. On the opposite side of the resistor ***3***, on the printed circuit board ***7*** of the voltage sensor, there is a voltage sensing resistor ***4***.

The resistors ***3*** (R_I) and 4 (R_U) are mechanically joined and there is a thin, non-conductive layer ***6*** between them. This design ensures virtually identical operating temperature t for the resistors. The resistors R_I and R_U are made of identical material (PCB copper foil) and have identical operating temperature which means that the ratio of resistors R_I/R_U does not depend on the temperature t and is constant.

Resistor bridge R_L, R6, R_I, R_U allow to calculate U_I/U_U ratio:

$$\frac{U_I}{U_U} = \frac{1}{Rsl} \times \frac{R_I}{R_U} \times R6\,, \tag{6}$$

where U_I - resistor R_I voltage drop,
U_U - - resistor R_U voltage drop,
R_L - consumer active resistance.

Describing part of the equitation (6) $R_I x R6/R_U$ as K, equitation (5) can be rewritten in to equation (7):

$$\frac{1}{K} \times \left(\frac{U_I1}{U_U1} + \frac{U_I2}{U_U2} + \ldots + \frac{U_IN}{U_UN}\right) = \frac{1}{R_{sum}}\,, \tag{7}$$

where U_I1, U_I2, ... , U_IN - each consumer device U_I value,
U_U1, U_U2, ... , U_UN - each consumer device U_U value,
K - factor, equal to $R_I x R6/R_U$.

By adding to equation (7) current I_{sum} and voltage U_{sum} values measured by electrical energy metering devices final equation is (8):

$$\frac{U_I1}{U_U1} + \frac{U_I2}{U_U2} + \ldots + \frac{U_IN}{U_UN} = \frac{I_{sum}}{U_{sum}} \times K\,. \tag{8}$$

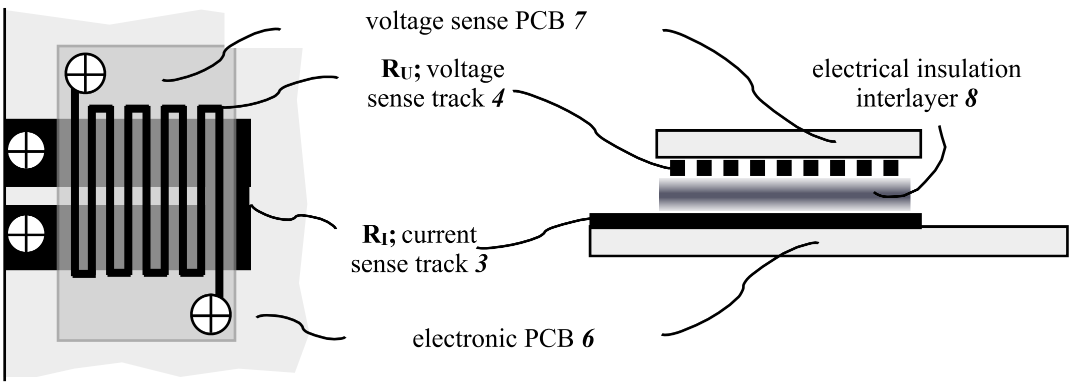


Fig.12. The transducer design

The consumption of each electricity consuming device as a share of the total consumption is monitored by monitoring the rations UuN/UiN in real time. This solution is used in electricity consumption monitoring systems.

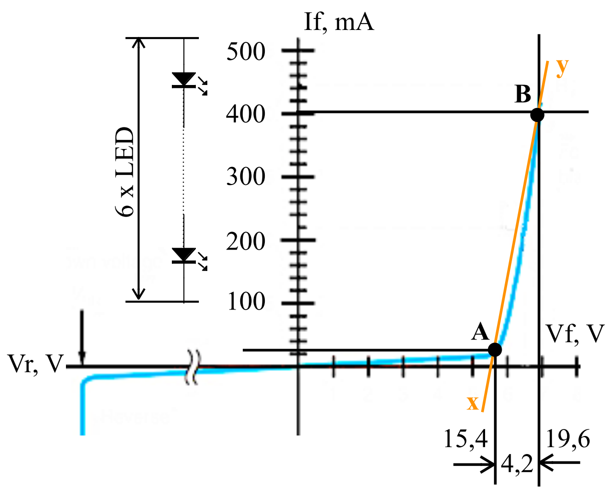
The main advantages are temperature stability, max load current is up to 10 A, small size and low production costs.

CHAPTER 4. EXPERIMENTAL RESEARCH ON WMCSEDS

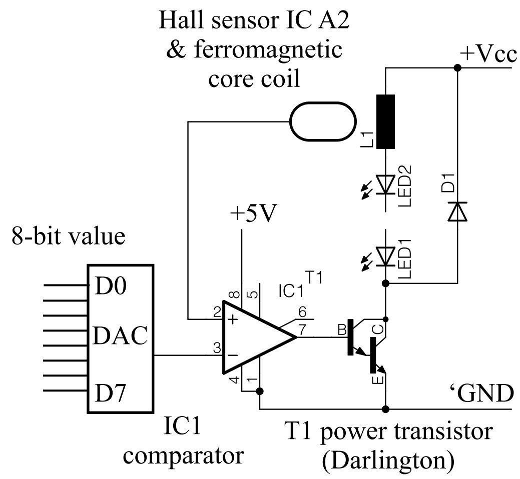
4.1. Lighting systems

The objective of a lighting system is to achieve for a practical or aesthetic effect necessary illumination. Illumination by LED luminaries can be dimmed similarly to incandescent bulbs, by controlling the LED current.

The volt-ampere characteristic of the LED string (6 LEDs in a series) is similar to that of a p-n junction. (Fig. 13).

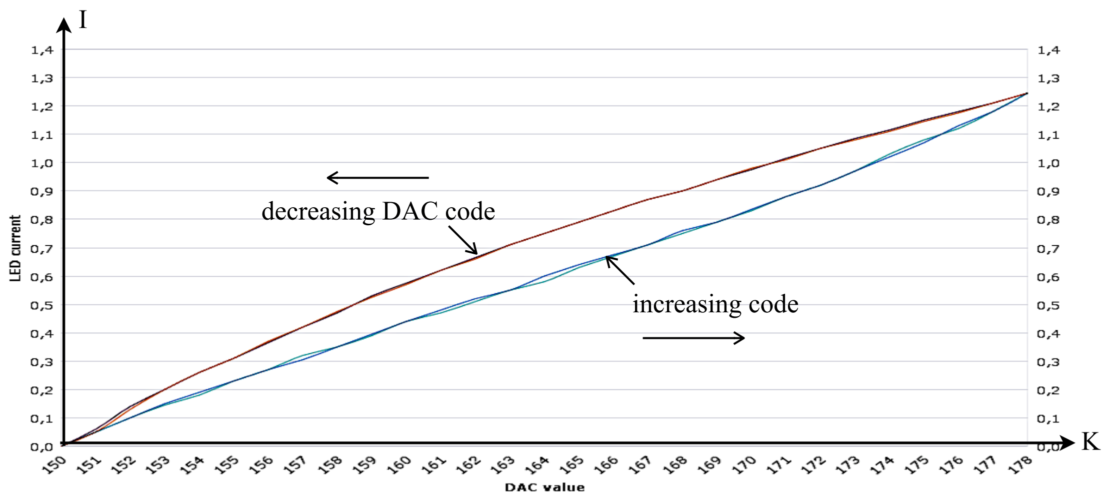


13. att. 6 LEDs string volt-ampere graph



14. att. Current regulator simplified circuit

LED current is determined by an 8-bit DAC input value determined by a WMCSED. The current regulator (Fig. 14) uses a Hall effect based non-contact magnetic flow sensor that is located within a ferromagnetic core coil. The characteristic of the regulator (Fig. 15) shows the influence of the magnetization curve and therefore the unsuitability of such a regulator for a WMCSED, since two current values correspond to one code value.



15. att. LED current **I** - binary code **K** graph, **K**- binary code decimal DAC value

Fig. 16 shows the functional diagram of LED luminary dimmer that is efficient and suited for a WMCSED. This is a SMPS circuit modified for PWM control.

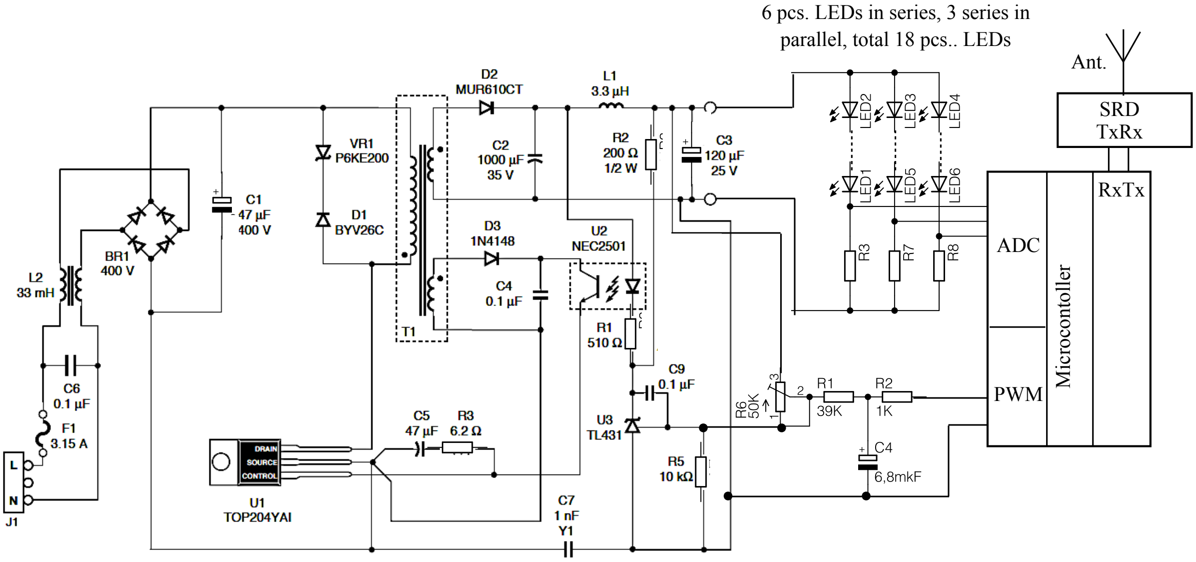


Fig.16. PWM controlled SMPS suited for a WMCSED.

The power supply consists of an integrated circuit U1 (TOP204) with an output voltage stabilization. The power supply is based on a flyback principle. This arrangement recommended by the manufacturer has been modified to change the output voltage value by a micro-controller generated PWM signal. This is ensured by a connection of the elements R1, R1 and C4. The PWM duty cycle can be controlled by using the SRD wireless data exchange.

The micro-controller also has a current stabilizer function, namely, it reads the current values in a LED series (voltage drops to R3, R7, R8) and calculates and modifies the PWM duty cycle accordingly.

The characteristics of an PWM controlled SPMS power supply are shown on Fig.17. Applying the quotient of 1/255 ranging from 15.4 to 19.6 V (Fig. 14). The measured and calculated efficiency of the power supply is 0.81-0.87, if the load currents are in the range of 0.08-1.1 A.

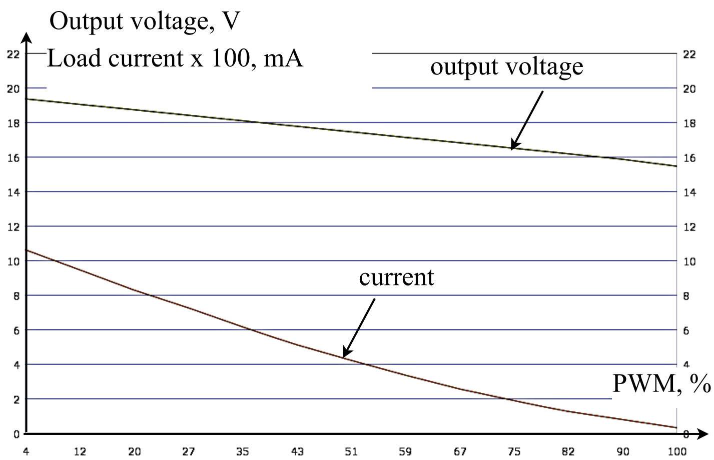


Fig.17. PWM controlled SMPS characteristics
LED load: 6 LEDs in series +2 Ω resistor,
3 strings in parallel

To increase the total power and reliability of the luminary three identical power supplies with a common control unit (common micro-controller and SRD transceiver) are used. If the power of the luminary exceeds 75 W the power factor must be corrected.

The WMCSED for the control of LED luminaries is performed by 900 MHz ZigBee and 433 MHz SRD transceivers in a star network.

The WMCSED control is performed by a “FileMaker” database.

When a ZigBee transceiver is used the data exchange time exceeds the maximum real time WMCSED value. The average time delay is 220 ms due to the low speed data transmission (9600bps). When a SRD transceiver is used the data exchange time does not exceed the real time WMCSED criterion because of a shorter packet length (83 ms).

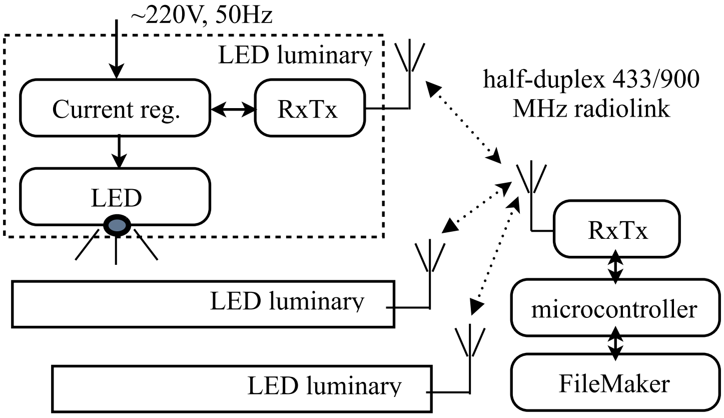


Fig.18. LED luminaries radiowave network

The LED luminaries power supplies with a significant hysteresis loop, e.g., the aforementioned stabilizer with a Hall sensor, are not suited for integration into a WMCSED.

The developed method for an PWM controlled stabilized voltage power supplies is easy to integrate into a WMCSED.

4.2. Monitoring system of the electricity consumption of electricity consuming devices.

The electricity consumption is characterized by the current of the electricity consuming device(3), (4). It is possible to develop WMCSEDs for consumption monitoring either as smart grid elements or as independent solutions.

If the load current of the electricity consuming device is sinusoidal then the load current active components obtain an amplitude value in moments when the voltage has an amplitude value at the waveform period point of π/2 or 90º (Fig. 19).

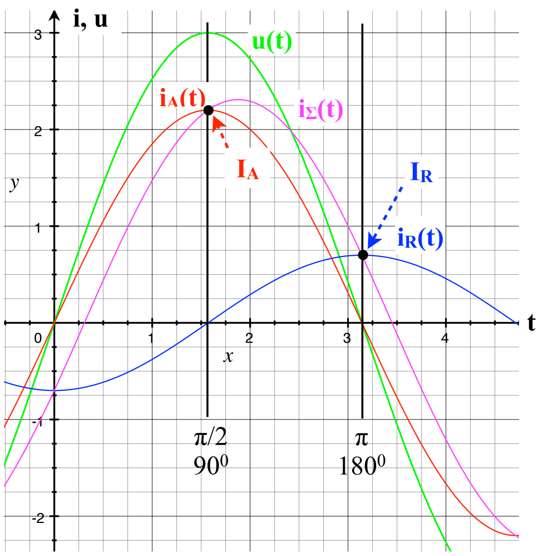


Fig.19. Sinusoidal voltage, active, reactive and total current graph

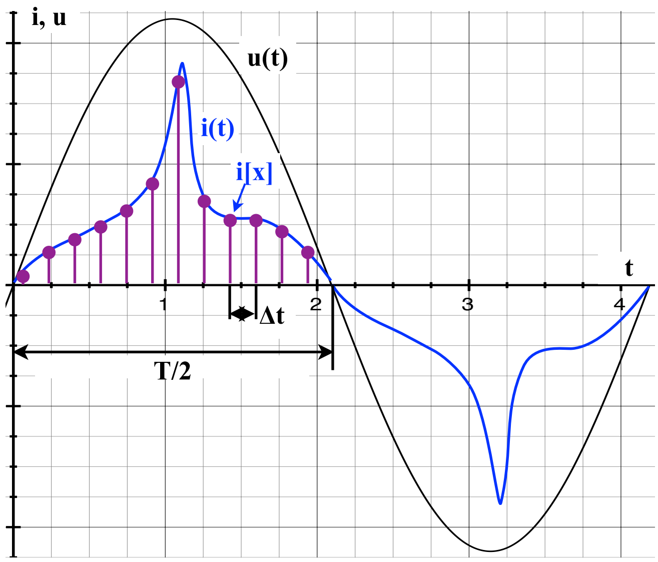


Fig.20. The consumer current instantaneous values

If the current is non-sinusoidal then the known discrete current values are obtained (Fig. 20) and mathematically processed by a micro-controller program.

The wireless modules ZR7AZ and ZF-1 (Fig. 21.) have specific characteristics due to their main function – they are used in alarm systems with a carrier frequency of 433 MHz:

- the data transmission rate does not exceed 31.25 kHz,
- the data code is transmitted twice (for reliability), which causes a delay of 150-200 ms (Table 2).

4-bit linear data transmission ensures the accuracy of 6.25% (1/16) which exceeds the projected accuracy of 2%.

6-bit linear data transmission (newest 3 bits first, then the oldest 3 bits) ensures the accuracy of 1.56% (1/64).

The energy consumption is monitored by the temperature compensated shunt described in the paragraph 3.2.

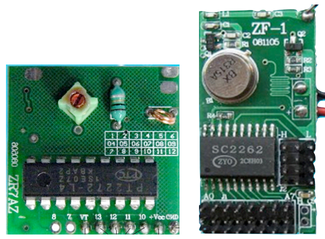


Fig.21. SDR transmitter-receiver modules

This solution provides low monitoring system costs if the number of electricity consuming devices is 8-10 or larger and have a common consumption metering system.

4.3. WMCSED in a wireless power transmission system

In order to supply power to a variety of sensors and mechanisms that are located on a moving part of a movable or rotating mechanical joint, e.g., on the axis of a stepping or servo motor, or on the rotating element of a robotic system, it is not possible to use the popular wire loops if the motion is 360º or more

Along with the know solutions here the energy transmission is provided by a system consisting of two inductive resonant circuits (Fig. 23). Inductances are generated by a core-less transformer (Fig. 22).

The primary H-bridge generates 31.5 kHz AC in the primary resonant circuit (resonant tank).

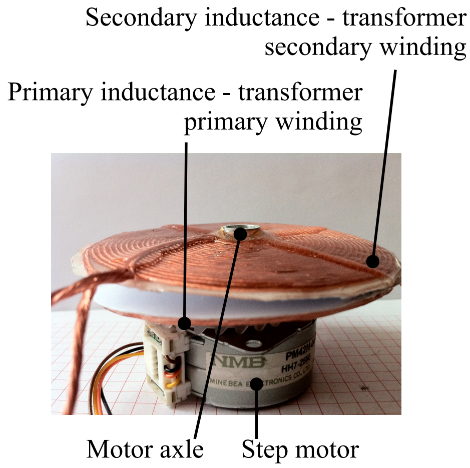


Fig.22. Resonant inductances

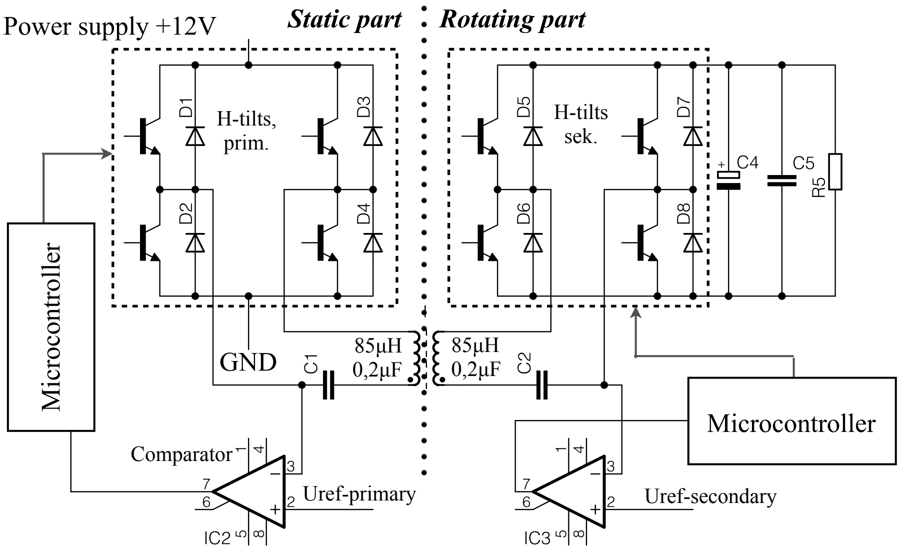


Fig. 23 Data over wireless power transmission system

The primary circuit current induces the AC in the coupled secondary resonant circuit rectified by clamp diodes of the secondary H-bridge. The transmitted energy is accumulated in to electrolytic capacitor C4.

The primary and the secondary H-bridges are modulated by the transmissible data. The data exchange rate is 14400 bps and the reception delay from the secondary unit is 48 ms. The power transmission efficiency does not exceed 78% and it depends on the information contained in a byte of the transmissible data.

This system is too complicated for wide deployment therefore it is more suited for cases when other solutions do not deliver the necessary outcome.

4.4. WMCSEDs in electrical engineering education

Practical training is of utmost importance in electrical engineering studies. However, because of the limited time possibilities the students end up with only a few hours per week or less. Fig. 24 shows the importance of the action in a knowledge creation process.

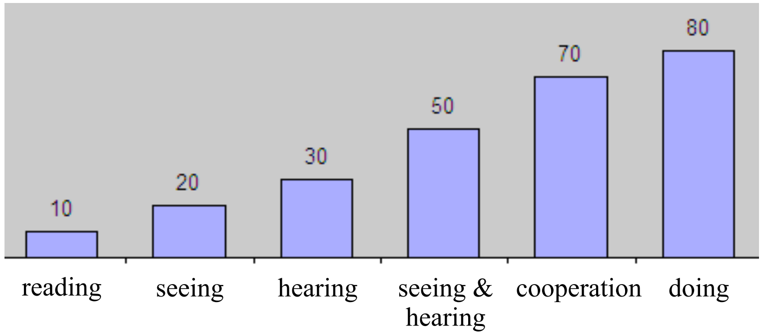
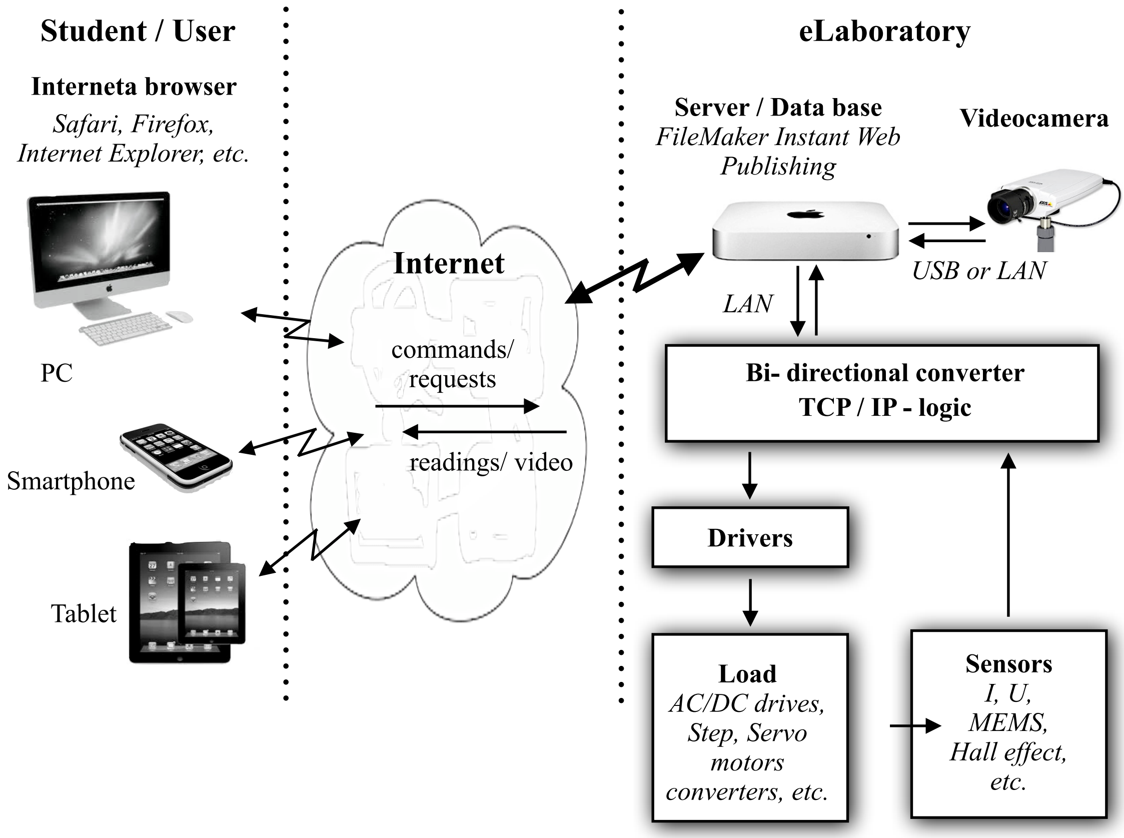


Fig.24. Knowledge creation

The objective of the e-Laboratory is to increase the share of practical training in a study process. Fig. 25 shows the process diagram.



5.1. att. Structure of the e-Laboratory

The functioning of the e-Lab equipment and the readings of the meters can be remotely observed by the way of a video camera that can be pan-tilt positioned by the student using his/ her own computer through internet or "FileMaker" software. Readings, calculations and graphical renderings are performed by the "FileMaker" software.

CONCLUSIONS

- ✳ The research on the developed wireless monitoring and control systems of electrotechnical devices (WMCSEDs) shows that it is possible to totally avoid the use of wired communication for control units and power electronics in cases where the time delays introduced by a WMCSED do not interfere with the functioning of the electrotechnical device.
- ✳ The direct WMCSEDs can be implemented by using a full duplex radio signal with analog or digital modulation.
- ✳ The WMCSEDs that simultaneously monitor several parameters or execute several commands can be implemented by using a half duplex or full duplex radio signal with analog or digital modulation.
- ✳ The main shortcomings of the direct WMCSEDs that can simultaneously monitor several parameters or execute several commands are: low resistance to radio interference, the necessity for high definition low frequency band filters and the limited dynamic range of the monitored parameters (<48 dB (<255:1)).
- ✳ The direct or WMCSEDs that can simultaneously monitor several parameters or execute several commands cannot be implemented by using the serial data communication and protocols due to the introduced time delays.
- ✳ The real time WMCSEDs can be implemented by using half duplex serial data radio communication modules. The communication range does not exceed 100 m.
- ✳ The real timeWMCSEDs cannot be implemented by using ZigBee/XBee modules because the time delay exceeds 180 ms.
- ✳ The universal WMCSEDs can be implement by using communication modules of any type because the introduced time delays are insignificant in comparison to the total duration of the process.
- ✳ Parameter sensors with a hysteresis loop generate dual output values and therefore are not suited for WMCSEDs.
- ✳ The relational database software “FileMaker” is suited for real time WMCSED control both locally and remotely, and this can reduce the time necessary for development of an WMCSED control by 30-50% depending on the specific solution.
- ✳ The developed temperature compensated shunt allows to reduce by 50-60% the WMCSED necessary for electricity consumption monitoring comparing to the existing solutions. The innovative character of this solution is attested by a positive opinion on patentability within a framework of PCT.
- ✳ The developed snake-like motion robotic device that uses an WMCSED for electric drive control allows to modify the profile of the module chain. No additional electricity consumption (e.g., electromagnetic brake) is required for profile sustenance. The innovative character of this solution is attested by an international PCT patent.
- ✳ Real time and universal WMCSED simplify the communication among devices required for remote practical workshops in electrical engineering studies, and facilitate their connection to the global public data exchange network: the internet.

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