An Example of Li-Fi Technology Implementation for Home Automation

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***Abstract*—The purpose of this paper is to describe an example of home automation system utilising electromagnetic interference-free Li-Fi optical wireless communications. The proposed home automation system solution is built upon KNX, which is one of the global industry-adopted building automation standards. The experimental setup was developed using Raspberry Pi minicomputers while communication modules were built using Arduino boards. Communication range was within ten meters which is sufficient for the majority of home automation cases.**

***Keywords*— home automation, knx, led, li-fi, sensor, smart home**

I. Introduction

Information technology is considered to be a key factor influencing economic and social development. Technology development evokes growing opportunities that raise user demands and the need for innovation. Although the notion of smart wiring is too widespread in many territories, over time, more and more systems are emerging on market that complement this industry. Innovative technologies for managing households and buildings are causing replacing conventional wiring with smart installations.

Intelligent installations combine technological progress, economic operation and unify building technologies, creating an efficient and user-friendly environment that takes user needs into account, and efficiently and economically manages the entire system. Creating such a functional system is financially more demanding, but offers more flexibility, return and prospects for the future.

The smart home concept has been well researched and developed in past years and emerged as an ultimate notion referring to all aspects of human life, which is smart living [1], [2]. Smart home is an important space among the other smart spaces due to the fact that big share of their lives people spend at home. A vast number of technological solutions are brought to ensure a high quality of human life. But that also raises concerns. Speaking of wireless radio technologies, one of the biggest concerns is the impact of those technologies on human health.

Many scientific electromagnetic radiation studies in conjunction with epidemiological experiments on individuals show undesirable biological consequences. These include increasing probability for getting cancer and memory problems, altered brainwave activity, insomnia, neurological disorders, reduced response time, severe headaches, ringing in the ears, weakness, chronic pain and fatigue, breathing difficulties, [3]. Because of the specified concerns, wireless non-radio technologies have a definite appearance among the other technologies used in smart living solutions, particularly – home automation.

The rest of the paper is arranged as follows. An introduction and basic description of selected smart home technologies is given in Section II. System design details are presented in Section III. Concluding remarks are gathered in Section IV.

II. Selected Smart Home Technologies

Automated control is an essential property of smart home technology implementations. Basic control functions, such as control of heating, ventilation, air conditioning, lighting and other systems may be integrated to Building Automation System (BAS). The purpose of BASs is to improve comfort, security and efficient energy management. Building automation is an excellent example of a distributed control system, where the main part consists of a computer and a network of electronic devices designed for tracking, control and security [4], [5].

The BAS maintains the climate of the building to a certain extent, controls the light in the lower rooms based on the data obtained from motion sensors located in the ceilings of the room, monitors the effective lighting performance and adjusts the intensity based on the outdoor lighting of the rooms.

A. KNX

KNX is part of the international standard protocol for home and industrial automation (ISO / IEC 14543, CENELEC EN 50090, CEN EN 13321-1, GB / Z 20965) based on the European Home System, EIB (European Bus Bus) , and BatiBus. It uses several types of transmission media such as power cable 230V, twisted pair, wireless and Ethernet. With the KNX system it can use different topologies and allow for flexible installation. An addressing system is designed for KNX. Each device in the KNX network must have a specific physical address and group address. Devices use a physical address for initialization, programming, and diagnostics, and the group address is used for common communication. Each device in normal operation communicates with multicast. This standard ensures compatibility of all products from different manufacturers and, above all, a worldwide network of providers and industry experts [6].

B. Differences between Li-Fi and Wi-Fi

Li-Fi is the term used to describe the visible light-communication technology applied to high-speed wireless connection. This name was obtained due to similarity to Wi-Fi however instead of the radio, light was used. Wi-Fi is excellent for wireless coverage inside buildings while Li-Fi is ideal for high coverage density in closed space and to reduce problems radio interference.

C. The principle of signal processing by Li-Fi

Visible Light Communication (VLC) - uses LEDs for wireless data transmission using intensity modulation (IM-modulating intent). The receiver detects a signal using a photodiode (PD) on the principle of direct detection (DD). VLC is conceived as a data flow for point-to-point communication - essentially as a cable replacement. These facts led to the normalization of VLC activity as part of IEEE 802.15.7 [7].This norm sets Li-Fi as a future standard.

Li-Fi, in contrast to the VLC, describes a complete wireless communication. This includes two-way multi-user communications, point to multipoint and multipoint to multipoint. Li-Fi also includes the form of multiple access points in very small optical microcells. It means that Li-Fi allows full user mobility and therefore creates a new layer within an existing heterogeneous wireless network. The fact that LEDs use natural light rays, enable signal blocking in one room only.

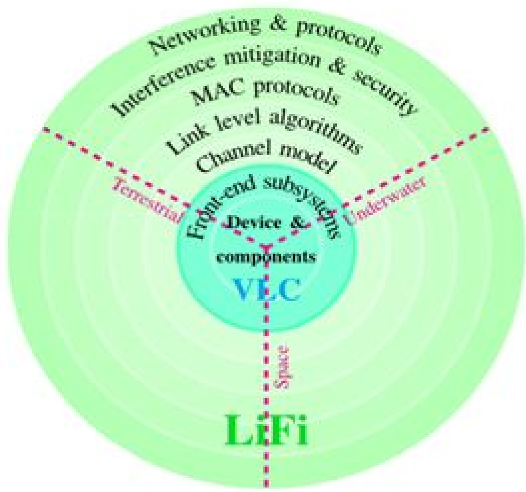

Fig 1: Principal building elements of Li-Fi and its application area [8]

D. System application for house

The design of the installation in a family house can be seen in Fig. 2, where Raspberry Pi forms the core of the whole system and connects two independent systems into a complex. On the one hand, it's a KNX bus which takes care of communicating with actuators, lamps, electronics and switches. On the other hand, it is the Li-Fi technology, which provides sensor communication with the Raspberry Pi control unit. For successful communication with the KNX, a KNX/IP converter is required communication between the Ethernet and the bus and mediates Raspberry Pi information. The whole system is designed so that, in the event of Raspberry Pi failure, the KNX bus could operate independently, and will not endanger the permanent operation of the house. However, it is only about controlling the light circuits and emergency heating. Heating in emergency mode is implemented through a simple thermostat that controls the operation of the pumps automatically. For manual control, the four-way valve is used to control the hot water. Thanks to the valve it is possible to regulate the inlet temperature for floor heating. The thermostat only controls the operation of the pump, it does not affect the floor water temperature.

The control unit of the house is implemented using Raspberry Pi, and without it the house behaves as if it contains only a standard TN-S electrical installation.

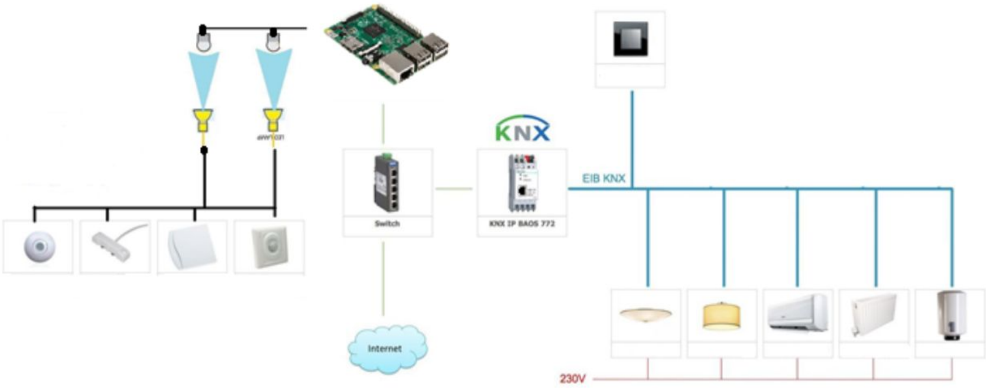

Fig. 2 Home system scheme

Fig. 1 illustrates the main techniques that are needed to establish a microcell within the Li-Fi network. There is a new device in the core like Gaul nitride (GAN), micro-LED and one photon. They are stored in an optical cylinder and used subsystems that include adaptive optics as well as analog circuits that control LEDs and shape signals received from the receiver. The consideration of co-channel interference (CCI) model allows accurate channel control and takes into account spectral signal composition [9]. To enable multi-user access, physical access to the medium (MAC) uses protocols that must have specific physical Li-Fi characters. Similarly, they are necessary mitigation techniques to ensure fair access to every device and high total system permeability. LiFi transmitters are generally designed not only for wireless communications, but also for lighting, which can be realized either by using a blue LED with a yellow coating or phosphorous colors mixed with color LEDs. Lamps equipped with various LEDs they can provide additional signal modulation and detection capabilities in Li-Fi systems [10]. The Color Shift (CSK) is the IM system shown in IEEE 802.15.7 [11], where signals are encoded to color intensities emitted by red, green, and blue LEDs (RGB). In CSK, they will incoming bits mapped to instant color LEDs while maintaining a constant the average bitrate for the received color. The advantages over the conventional CSK IM system have two properties:

- Constant luminous flux is guaranteed, there will be no blinking effect for all frequencies.
- Constant luminous flux means almost constant excitation current for LEDs, which reduces possible switching current at signal modulation, thereby increasing LED reliability.

In terms of maximizing communication capability, color intensity modulation (CIM) is designed in [12] orthogonal and non-orthogonal optical channels.

III. Design

The previous chapters was describe the theoretical knowledge that can be used to design a solution to create an affordable functional system that meets the basic requirements of an intelligent home management and management system.

The proposal is to manage an average family home. The task was to design a system that will be affordable and at the same time provide the smart homeowner's expected cost savings and improved safety and comfort. The main problems that may arise during the design are the unsuitable cabling. It depends on whether it is a new building or a reconstruction of an older house. Each room had to install a temperature, humidity and ambient light sensor. These sensors must communicate with the central unit, which in this case is the third generation of Raspberry Pi.

During the presentation of the design for an older house, other cables were strictly rejected by the house owners. it was only expecting wireless technology. Because of the fear of an ever-growing wireless smog in the house. The appropriate technology for the home was Li-Fi. This technology allow wirelessly transmitting data only with the help of light and not bothering the environment by electromagnetic radiation waves. The implementation is rather focused on data transmission in both directions and the data transmission solution is being investigated from the terminal equipment. The system does not need two-way communication, just one-way communication from the sensor to the central unit. The sensors were placed in the ceiling lights and connected to the existing room lighting. The classic bulbs had to be replaced with LED bulbs to allow transmission. The main goal was to design and implement a Raspberry Pi programming system that provides intelligent house features and creates a user-friendly environment for intelligent house design and management.

A. *The principle of signal processing by Li-Fi*

The first construction phase was communicated via serial communication with the Arduino board. The whole system was designed with existing modules for the Arduino system and the data transmission speed and the measured achievable distance were tested for the feasibility of the data transmission. No high transfer rate is required for sensors. The system uses an 8-bit message to send temperature and humidity information. Key design features:

- Data transfer is performed at a serial line at 38400 bps for sensors
- Acceptable communication range is between 1 meter and 10 meters
- Low power consumption
- EMC compatible
- Better security due to less signal outside the room (compared to WiFi)
- High bandwidth available due to light spectrum used

A transmitting and receiving part was required to transmit the data.

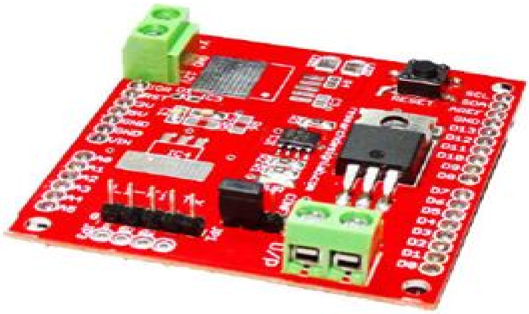

Fig. 3 Arduino-based transmission controller

A transmission controller is shown in Fig.3. It is connected to the LED board (Fig. 4), which performs the actual data transmission. The data is received by the receiving module. Because the microcontroller is not able to supply a large amount of current, the board contains a transistor to quickly switch logical values.

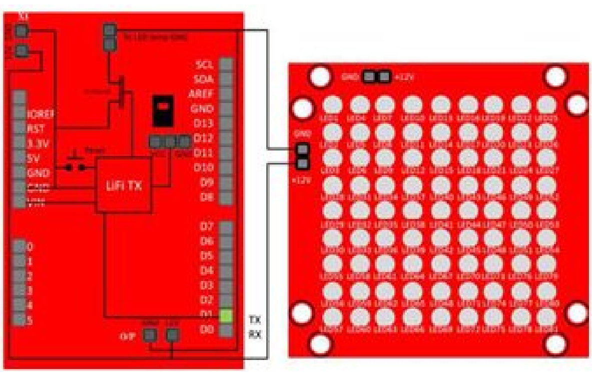

Fig. 4 Connection LED board to Arduino

The receiving part of the system has sensitive photodiodes that process the received information. Photodiode claims are spectral sensitivity in the visible spectrum and fast response time. Also, the size of the sensitive area is very critical, so the VISHAY BPW21R [13] diode was used. At a maximum wavelength of 565 nm, it has the right sensitivity. It provides an appropriate range for use because it has a spectral bandwidth of 420 nm to 675 nm. It has a more sensitive area of radiation than most of the photodiodes - 7.5 mm^2. The diode has a rise and fall time of 3μs, allowing switching at a frequency of 166 kHz. The board can accept a voltage of up to 5 V. The receiver converts the current into a voltage and is equipped with a circuit for automatic control of the received signal.

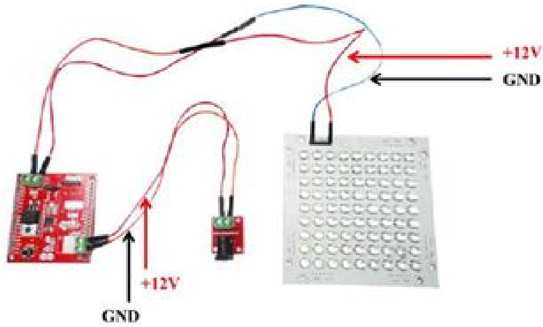

Fig. 5 Experimental setup

Experimental connection was made by connecting the LED field to the Arduino system. The engagement can be seen in Fig. 5. When testing the speed and range of connections, it was found that the connection was feasible up to almost 10 meters, with the transmission rate being almost constant until the connection was interrupted. In experiments, it was found that the transmission was most disturbed by the remote control from a TV that uses infrared LEDs to transmit codes. This interference can be avoided by suitable LEDs in the transmission matrix. The most suitable LEDs in the experiment fell on those that shone in the visible spectrum. All the measured values were processed in the following graph.

Fig. 6 Graph of transmission rate

The results of the experimental measurement of the Arduino Li-Fi system were verified by an oscilloscope.

Fig. 7 shows the signal from the transmitting and receiving sections. The received signal is almost the same as the transmitted signal. It is possible to see a small phase shift between the broadcast and the received signal. This is caused by wireless channel noise and capacitive effects. The transmission efficiency can be measured in terms of received and transmitted power. The transmitted power is 0.8 watts and the received power is 0.05 watts at the photodiode. Efficiency is the ratio of the received power to the broadcast. Transmission efficiency is 0.0625 or 6.25%.

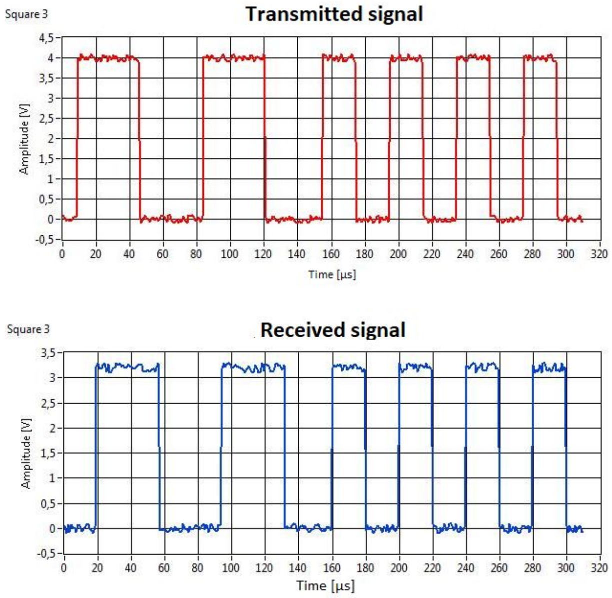

Fig 7: Example of transmitted and received signal

The transmitter receives data from the computer via a USB connection and is then processed by GPIO pins on Arduino, the signal is controlled by a transistor that turns the LEDs on and off. Voltage values can be either 12 V or 5 V for LEDs power, but more preferably 5 V for low power operation.

On the receiving side, the received light is converted to an electrical signal. The signal is in analogue form and has to go through the analog-digital converter. The current from the photodiodes is very low, and it is necessary to use a high resistance value for the conversion to voltage. This voltage is amplified for use in a comparator to detect the correct bit value.

IV. Conclusions

The implementation of home automation system built upon the KNX standard is described in this paper. The system utilises Li-Fi optical wireless communications. A great benefit of Li-Fi is electromagnetic interference-free communication. The control unit of the system is implemented using Raspberry Pi, and wireless communication modules are built using Arduino boards.

The proposed home automation system was tested in the real house, and all experimental results are collected and verified. The achieved transmission efficiency is 6.25%, which is sufficient for binary communications within a range of ten meters.

The use of Li-Fi technology can help people reduce electromagnetic radiation at home. The drawback of the technology is its limited data transfer rate, with is up to 96 Mbit/s as it is defined in the PHY 3. This limitation does not have a negative impact on the use of Li-Fi as the basis for home automation communication channel but may limit the use of Li-Fi in modern multimedia communications requiring high bandwidth.

Acknowledgment

This work was supported by Cultural and Educational Grant Agency (KEGA) of the Ministry of Education, Science, Research and Sport of the Slovak Republic under the project No. 062TUKE-4/2017 and the project No. 023TUKE-4/2017.

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