Prototype of a luxmeter with high sensitivity suitable for long-term data recording

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***Abstract* – This This paper describes the development and testing of HK-01 Data Logger luxmeter. This luxmeter is able to operate automatically and record obtained data. This device is used to measure illuminance and it is characterized by a wide range, from 10mlx to 100klx. Its resolution is 1mlx. This device makes possible both manual and automatic range setting, as well as recording obtained values into the luxmeter´s internal memory, either automatically in set time intervals, or manually. Recorded data can be viewed on the display, or exported into a computer. Furthermore, this paper describes the testing of this luxmeter in a photometric laboratory, looking especially at its directional pattern and spectral qualities. The testing was carried out with the use of JETI specbox 1211 professional spectroradiometer.**

Keywords-Photometry; Optical senzors; Illuminance; Microcontroller

I. Introduction

This article describes proposal and execution of luxmeter that is suitable for long-term evaluation of the state of obtrusive light at night. Objective evaluation of obtrusive light is gathering information on its effects in different locations and weather conditions. It mainly concerns the effect of public lighting. However, not only this source affects the luminance of the night sky. It is necessary to take into account the influence of other light sources such as windows, neon signs, commercial and industrial centres, etc.

Luxmeter development which meets the requirements for long-term measurement of very low levels of illuminance was caused by the impossibility to obtain such device on the market of measuring instruments. Measuring instruments available on the market, meeting the requirements for measuring low levels of illuminance, did not meet other requirements, which were mainly related to long-term data collection.

II. Specification of the main requirements for the digital luxmeter development

When designing the concept of digital luxmeter the following requirements were taken into account:

- The curve sensitivity of the human eye for photopic vision - although the luxmeter has been primarily designed for measuring low levels of illuminance, which may correspond to brightness circumstances in which the human eye is located in mesopic to scotopic vision, so the sensor evaluating the incident radiation has been chosen according to the sensitivity curve of the human eye for photopic vision. The reason for this fundamental decision was the possibility of comparing the measured data with other devices.
- Wide measuring range from 10^{-2} lx to 10^{5} lx - is usable in the long-term measurements for illuminance acquiring not only at night but also during daylight hours.
- Possibility of zero calibration - set to zero when measuring low levels of illuminance is necessary in this type of device.
- Long-term unattended operation - long-term operation is understood to detect illuminance levels under the night sky in various weather conditions, which makes it necessary to use fully autonomous operation.
- Power supply from battery or mains supply - power supply from the battery is necessary for field measurements with operation, i.e. the short-term measurements.
- Automatic range switching - is directly related to the measurement of illuminance even under daytime sky, which has great dynamics and for correct long-term measurements is necessary.
- Possibility of saving the measured data in memory and their later transfer to a computer - this feature is very well utilized in conjunction with real time clock with outdoor measurements.
- Ability to measure together with sending the measured data to a PC – has appeared in requirements due to measuring of rapid changes of illuminance, especially when verifying start-up characteristics of light sources.
- LCD display.
- Real time clock independent on luxmeter power supply - are very important in terms of comparing the measured data from different locations with the assumption that these locations are meteorologically near and

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presumably the same conditions reflecting the sky [1], [2], [3], [4].

III. The Hardware Part of the Digital Luxmeter

The basic part of luxmeter with high sensitivity (the ability to evaluate illuminance about 10^{-2} lx) is a quality sensor that is adapted by its sensitivity to the sensitivity curve of the human eye. If the sensor is not of sufficient quality, it is not possible to objectively evaluate illuminance not even by the best electronic circuit.

The Fig. 1 shows a block diagram of the luxmeter connection, which consists of the following main blocks:

- Measurement block,
- Microcontroller ATMEGA168,
- User interface,
- Real time clock,
- EEPROM memory,
- USB communication,
- Power supply.

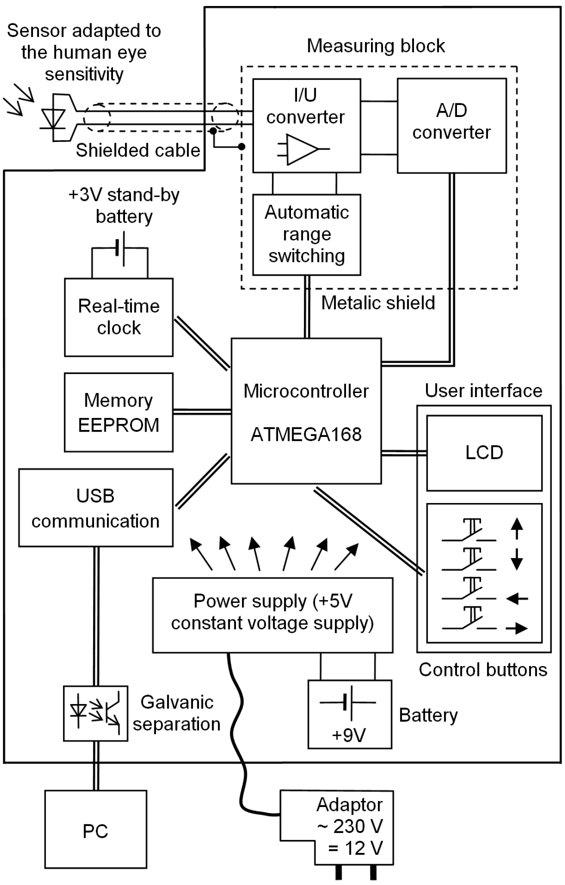

Figure 1. Block diagram of luxmeter connection.

<u>Measurement block</u> consists of converter I/U, electronic switch of ranges and A/D converter. In order to ensure linear conversion of illuminance to electrical variable even from a very small values of illuminance, the current is evaluated at the output of the sensor, and if possible in a state short. This can be implemented by current-voltage converter with an operational amplifier. Currents, with whom the converter operates in the illuminances up to 1 lx are, however, very small, of the order of nA. To work with such small currents the operational amplifier must be able to evaluate very small input currents, preferably several orders smaller than the operating current. These requirements meet the operational amplifiers with FET inputs. Other important parameters, that must meet the operational amplifier is the smallest noise and drift. In order to operate the operational amplifier from a battery power, it must operate smoothly even at a low supply voltage. These requirements best suited operational amplifier AD822. Due to the maximum limit of external interference (ensuring sufficient accuracy) is the analogue part of the luxmeter shielded. To switch ranges the analog electronic switch ADG728 is used, whose five inputs and one output are connected in the feedback of operational amplifier AD822. Range switching is done through serially controlled I^2C interface which is served by ATMEGA168 microcontroller. The analog value from the operational amplifier is further converted to a digital value using the highly accurate 18-bit AD converter MCP3421, which is also controlled by the microcontroller through I2C serial interface.

<u>Microcontroller ATMEGA168</u> by the ATMEL company ensures operation of the individual peripherals, which include electronic switch ranges, A/D converter, LCD display, four control buttons, real time clock, EEPROM memory and communication with the computer.

<u>The user interface</u> includes an LCD display and four control buttons.

<u>Real time clock</u> conveys current information that include the date and time and forms a circuit DS1338. To enable real-time clock to work even when the supply voltage is off, the DS1338 circuit is powered from the 3V stand-by battery.

<u>EEPROM memory</u> - is used serially programmable memory AT24C1024 to store the measured illuminance values in certain time.

<u>USB communication</u> between the microcontroller and the computer is enabled by RS232/USB converter, which is formed by FT232RL circuit. Data communication between the microcontroller and the converter RS232/USB is galvanically isolated using two optocouplers. To the power supply circuit FT232RL is used 5V power from the computer, which is normally supplied through the USB cable.

IV. User Menu of Digital Luxmeter

When designing th When you first turn the luxmeter on the LCD screen shows the value of lighting in Auto mode and also information about the current time and date. By using the Up/Down button it is possible to switch from the auto mode switching ranges on to a mode of manual settings with ranges up to 3 lx, 30 lx, 300 lx, 3 klx, 30 klx, 120 klx. By using the Left key we see the user menu containing the following menu: Offset cal., Set backlight, Set date, Set time, Datalog period, Start Datalog, Stop Datalog, Measured data, USB communication.

V. EXPERIMENTAL MEASUREMENTS

A testing kit (printed circuit board) had to be designed for the measurements. The main meter was a JETI specbox 1211 spectroradiometer, based on which the observed data could be evaluated. All measured data from the HK-01 Data Logger luxmeter were transmitted to and stored by a laptop.

For practical application, any illuminance sensor must possess some important properties, some of which are not optical properties. Nevertheless, they must be taken into account when selecting a sensor. They include, but are not limited to, resistance against interferences, supply voltage magnitude, operational temperature range, output information transmission method (analog-current or analog-voltage based; digital - communication interface type).

Among optical properties, linearity and the associated range are parameters of prime importance. One of the basic properties of any sensor, linearity should be assured from the factory. In the measurements, linearity was tested so that the kit with the sensor was illuminated from a direct light source whose distance from the kit was varied. A halogen lamp with constant supply voltage served as the light source.

The directional response pattern is another important optical property, showing how the sensitivity of the sensor changes in dependence on the light incidence angle. Theoretically, the angular dependence of illuminance for a planar surface hit by constant radiation under different angles should follow the cosine function. This should ideally apply (if reflection is neglected) also to a sensor whose sensing plane is a planar plate. In other words, the sensor should exhibit a cosine pattern. Ideally the directional response pattern should be the same in all directions. The side from which light hits the sensor is irrelevant, and the only relevant factor is the angle of incidence.

For our directional response pattern measurement the kit with the sensor was fixed to a rotary system. This system allowed us to rotate the kit around the vertical (as well as horizontal) axis and read the angle of rotation with an accuracy of 1 degree. When rotating the kit about the horizontal axis, the kit could be rotated about the transverse as well as longitudinal axis. This allowed us to examine whether the directional response patterns in the two axes are identical. Again, illumination was achieved by using a halogen lamp under constant voltage, positioned at the same distance. The diagrams in Figs. 2 and 3 demonstrate that the sensor directional response pattern approaches the cosine function fairly closely.

On the whole, the directional response pattern is satisfactory for the sensor tested by us.

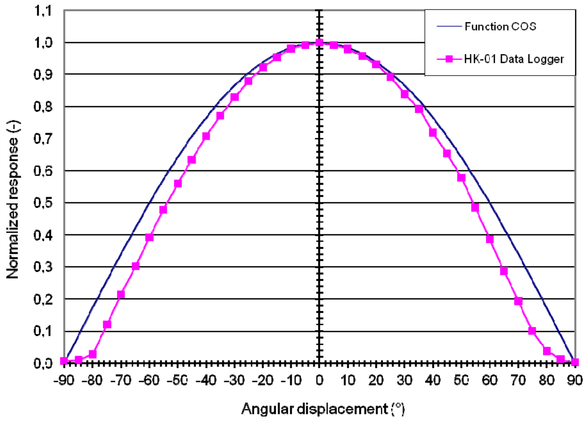

Figure 2. Measurement of the sensors' directional response patterns – horizontal axis of rotation.

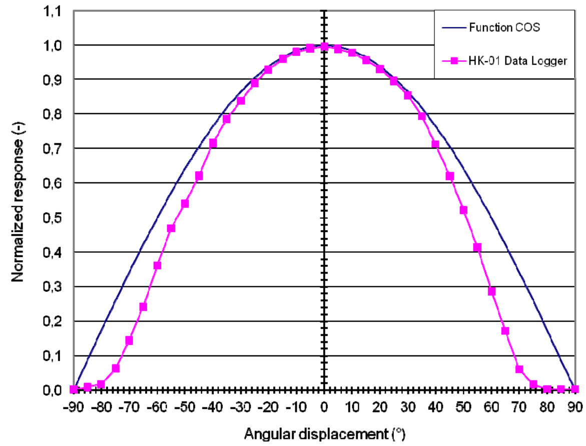

Figure 3. Measurement of the sensors' directional response patterns – vertical axis of rotation.

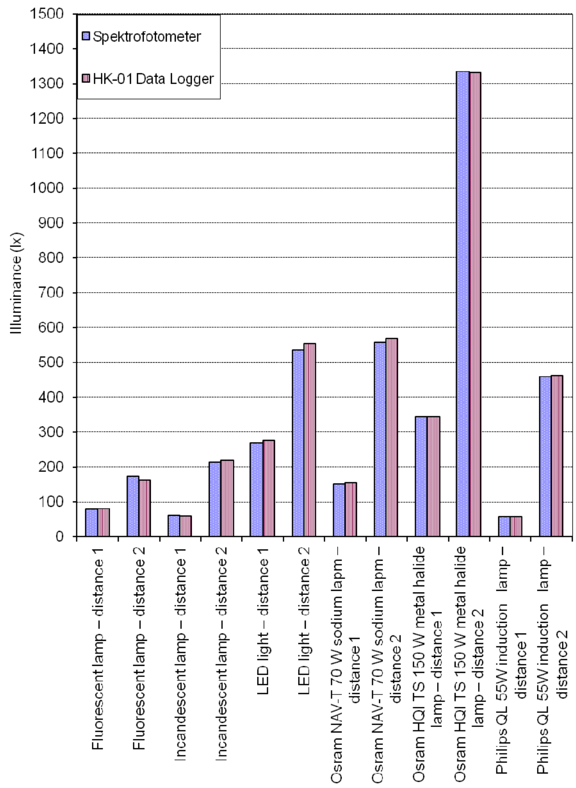

Figure 4. Response of the light sensors to different light sources.

The last examined property of the light sensor, which is of importance particularly in artificial light measurements, was the spectral characteristics.

We measured the spectral properties of the sensor by using selected light sources roughly covering the portfolio of most widespread sources, such as incandescent lamp, fluorescent lamp, LED, and various types of discharge lamps. Each light source was measured from more than one distance to enable us to statistically eliminate random errors [6], [7].

A Jeti specbox 1211 spectroradiometer, whose observed illuminance data should approach the true values closely irrespective of the light's spectral composition, served as the reference meter.

The results obtained for the sensor and the selected light sources are shown in the bar graphs in Fig. 4. The illuminance deviations (in percent values) for the selected light sources are shown in Fig. 5.

The HK-01 Data Logger luxmeter provided very good results, particularly owing to the fact that it contains a professionally manufactured photometric sensor with built-in correction filters. However, this sensor is too expensive for application to lighting intensity control purposes.

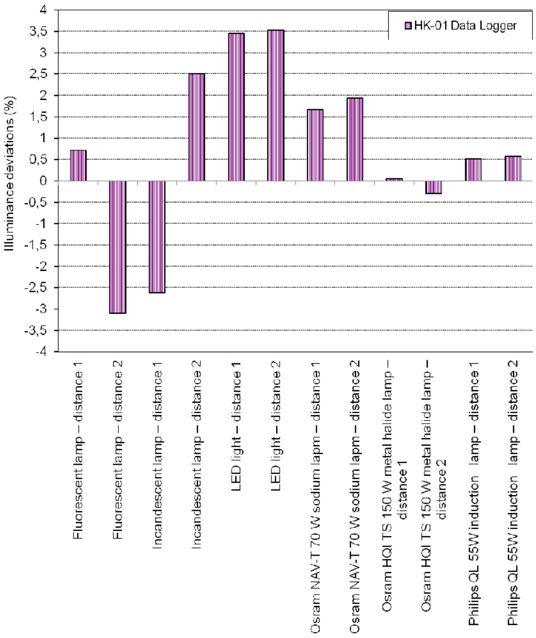

Figure 5. Response of the light sensors to the light of different light sources, with illuminance deviations expressed in percent values.

VI. PHOTODOCUMENTATION OF THE IMPLEMENTED DIGITAL LUXMETER

The Fig. 6 shows the shouldered printed circuit board of digital luxmeter when viewed from top layer. LCD display shows the first part of menu of the user menu.

VII. CONCLUSION

The HK-01 Data Logger luxmeter described in this paper can be used to carry out a number of light-technical measurements. Thanks to the option of automatic operation and recording, it is also suitable for long- term automatic measurement, which is not possible in the case of most factory made luxmeters. Its wide measuring range makes this luxmeter the ideal choice for measurement outside the range of common luxmeters. It can be used for scientific purposes, e.g. investigating light-technical parameters of the night sky, as well as in laboratory conditions, e.g. testing of luminaries, or testing light conditions inside buildings. The accuracy and other qualities of this device are very good, which is also dealt with in this article. That is due to the use of a professional photometric sensor equipped with correction filters - of course, these sensors are relatively costly, about 250 EUR. This device is used at our University and in the future it may be used by others as well. Up to date, the results of its use have been very satisfactory.

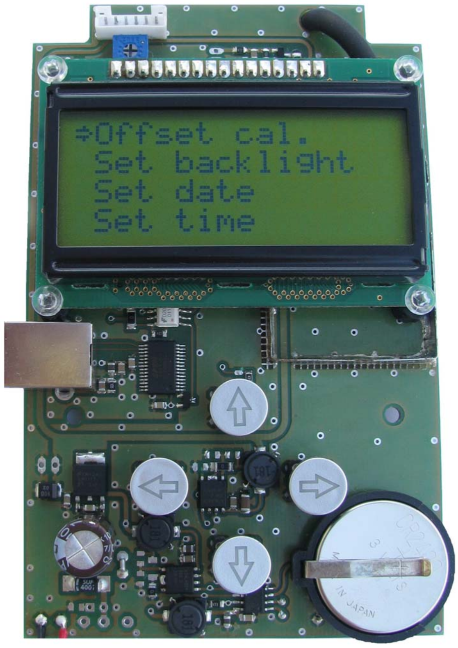

Figure 6. Shouldered printed circuit board of HK-01 Data Logger luxmeter

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