Human Circadian Rhythm Friendly Adaptive Spectrum Wake-up Clock Lighting

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***Abstract*— This paper aimed to show the theoretical background, the methodology and a practical realization of a spectrum optimized alarm clock that simulates a sunrise, for a more pleasant awakening. The shown internal light source is a surface mount RGBW led strip for supplementary lighting, due to the placement, the light is scattered light reflected from the surface. The article describes the relationship between the system hardware and software components, also dealing with design possibilities. The proposed methods and solutions are well applicable in other real-life applications.**

Keywords— sunrise alarm clock, wake-up light, adaptive sunrise emulation, dawn simulation, indoor environment lighting, lighting microclimate, light spectrum adjustment, light spectrum optimization, circadian rhythm, circadian clock

I. Introduction

In modern societies, people are increasingly exposed to artificial light that differs from the spectrum of natural light. Many scientific studies have highlighted its potential adverse health effects [1-3], light spectral effects can also be detected in animals [4].

Melatonin is the hormone that controls the sleep cycle, increases the length of the REM cycle, affects body temperature and causes sleepiness, and also affects the functioning of the immune system. The body need to sleep in darkness, exposure to artificial light at night (ALAN) may be one reason for the higher rates of modern health issues [5].

There are various methods to determine the spectral composition of light and to determine and measure the wavelengths that affect humans mentally and physically [6].

Modern human environment is full of light pollution, and it is modifying the physiological clock which is developed for thousands of years. This alteration is known as chronodisruption. Many LED based electrical light bulbs emits short wavelength illumination that the human body has not experienced in the past. Experiments shown that blue-free white light-emitting diode can prevent melatonin production shifting. [7]

It is important to choose the appropriate light spectrum for activities related to work [9, 10], education [11, 12], and rest [13], and it is also necessary to adjust its properties [14, 15]. In engineering practice [16], resource-efficient microcontroller control [17, 18] and closed-loop controls [19, 20] require for a good solution to perform the task.

II. Theoretical Background

Sunlight is produced in the interior of the Sun during nuclear fusion, and leaves the outer surface of the Sun in the form of solar radiation. The intensity of this radiation varies over the Earth's surface as a consequence of the complex regional relationships of local climate, solar radiation, temperature, cloud cover and prevailing winds [21-23].

Anticipating light conditions is important because it allows the plant to prepare its metabolism in advance for upcoming demands, so that the most resources for photosynthesis are allocated when they are most needed. Light also provides information about the structure and quality of the local ecosystem. Infrared light enables plants to optimize shadow avoidance strategies and sense space. Due to the different absorption and reflection properties of different objects, plants are able to distinguish a non-living object from other plants. [24]

In addition to its role in vision and photosynthesis, sunlight also provides UV radiation. [26] Exposure of the skin to UV light in the 280 nm - 320 nm wavelength range of the spectrum produces vitamin D and improves mood through serotonin production [27]. Nitric oxide production also starts in the skin exposed to UV light, which causes blood vessels to dilate and blood pressure to drop [28]. Most window glass does not transmit UVB radiation and significantly reduces UVA radiation.

The human eye perceives the range of sunlight between 380 nm and 780 nm. The actual effect of sunlight on humans depends on many variables, including the physiology of the eye, the way the light arrives (direct, transmitted or reflected), the intensity of the spectral components, their relative ratio and the angle of arrival, as well as the color and reflectance of the reflective surfaces.

Retinal ganglion cells (sensitive to light, especially wavelengths in the blue range) are directly connected to the internal biological clock in the suprachiasmatic nuclei of the human brain [29]. The blue light content of sunlight changes throughout the day, which acts as an environmental signal to maintain the circadian rhythm.

The peripheral circadian oscillator of humans regulates physiological and behavioral rhythms with a 24-hour period. To stay in sync, it needs sunlight for evolutionary reasons. Artificial lighting disrupts natural time synchronization. Neurons promoting wakefulness and sleep are connected to the suprachiasmatic nuclei (PCN) mechanism in the hypothalamus. Glutamate neurotransmitter signaling activates wake-promoting neurons and their associated neurotransmitters [30].

Light quality affects alertness, depending on light intensity, duration of exposure, and spectral composition.

The extent of the light's effect depends on the amount of time spent awake and physical activity. The photoreceptor cell type ipRGC in the inner retina contains the light-sensitive photopigment melanopsin, which contributes to vision by distinguishing between light and dark. In the early morning hours, light can advance the circadian clock, and evening light can delay it [31]. Contradictory signals can have serious physiological consequences.

The absence of artificial light during sleep is important for healthy sleep. Dawn and dusk, marking the transition between day and night, are important time synchronisms in terms of falling asleep and waking up. The twilight transition is disturbed by blue-enriched artificial light from artificial sources [32]. Software that changes the color temperature of screens leads to an earlier onset of sleep and a longer sleep time.

A. *Visual perception*

In addition to light perception, visual comfort also interacts with temperature, noise and air quality. The quality of light is affected by brightness, intensity, spectrum, flicker frequency, contrast, light distribution. Visual comfort is influenced by an individual's physical characteristics and mental state, for example: gender, age, medical history, visual ability, mood and cultural conditions, work tasks, stress, socio-economic status and social relationships.

Light can influence a person's psychological and cognitive functions, i.e. it increases alertness, awareness, mental performance, subjective well-being and the feeling of vitality. Brighter lighting leads to better visual and cognitive performance both during the day and at night [33]. Stronger illumination can also cause blinding light, which causes visual discomfort, obstructs vision, visual disturbances and even headaches, which burdens the individual and damages mental processes.

Individual light exposure preferences and needs depend on the pigmentation of the iris, the ability of the pupil to dilate, the quality of the optical medium of the eye, and individual genetic differences [34]. Diet, metabolism, and state of health can affect sensitivity to light for each individual.

B. *Harmful health effects of light*

It shifts the timing of the SCN of the organs and organ systems (peripheral biological clocks), so they can be mistimed in relation to each other, which processes can become disturbed. Light also regulates immune function, directly and through the circadian clock [35]. Due to poorly timed metabolic processes, insulin and cortisol are not secreted at the right time, increasing the likelihood of developing insulin resistance and type 2 diabetes [36].

Insufficient light can also cause harmful effects. Light affects neurotransmitters such as serotonin, which is produced by serotonergic neurons in the central nervous system and enterochromaffin cells in the gastrointestinal tract. The turnover of serotonin in the brain is the lowest in winter, as a result of which recurring seasonal depressive symptoms can develop, which is called seasonal affectiveness disorder (SAD) [37]. This is a form of depression, during the winter months, typically found in the northern hemisphere and triggered by the seasonal availability of sunlight, which artificial light therapy is effective in treating.

C. *Artificial indoor lighting requirements*

Good indoor area lighting exerts an impact on visual comfort, which contributes to overall psychological well-being and productivity of a person. For healthy workspaces it is also strongly recommended to use a purpose specific lighting microclimate. General quantitative and qualitative parameters for indoor illumination include:

- lighting value corresponding to the type of work,
- proper distribution of light in the area,
- preventing the creation of glare,
- light spectrum corresponding to the activity,
- appropriate brightness change over time (if necessary),
- appropriate spectrum change over time (if necessary),
- suitable orientation in case of local lighting,
- reliable and reasonable lighting architecture.

III. HARDWARE AND SOFTWARE IMPLEMENTATION

The control unit is a microcontroller, the firmware is written on an open source platform [38-42]. The LED driver circuits are based on PWM controlled MOSFET drivers. The red, green, blue and the warm white is the software adjusted channel. The light brightness and light spectrum sensors are directed to the measured surface. The power supply of the application area is a 12V high current PSU. The system architecture can be seen in Fig.1.

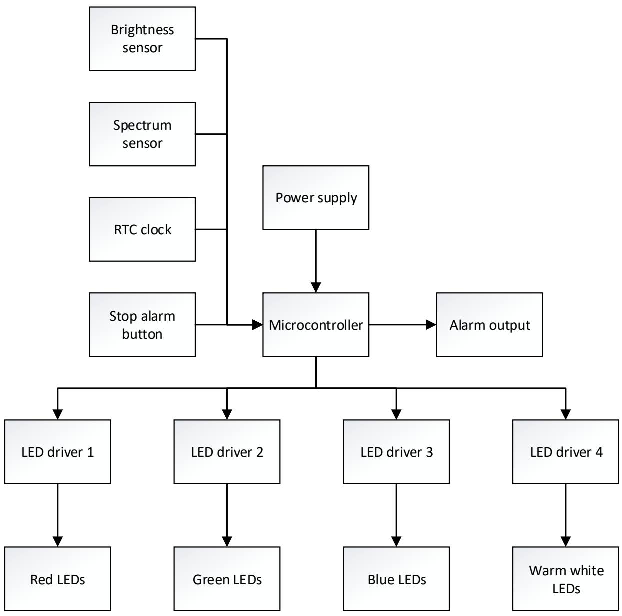

Figure 1. Connections between the system modules

A. *Light intensity and spectral change*

Light emitting diodes emit light in a narrow band of the spectrum, but with proper driving it is possible to emulate dawn with a continuous spectrum change. Also taking into account the effect of possible external light sources, a control loop [43-46] is made in software, to adjust the current spectrum and brightness level.

The light arriving at the sensor contains inter-reflection of light between various surfaces in space. [47] Due to the principle of measurement, the color shades of objects and furniture in the room or in the application environment do not influence the method of setting the light properties.

In case the application is a wake-up clock, the sensors are mounted next to the sleeping area, and directed to the ceiling. The LED strips are mounted to the suspended ceiling, the emitted light reaching the target surface after reflecting the ceiling, so the light source is not visible, it does not dazzle. A changing over time spectral transition can be seen on Fig. 2.

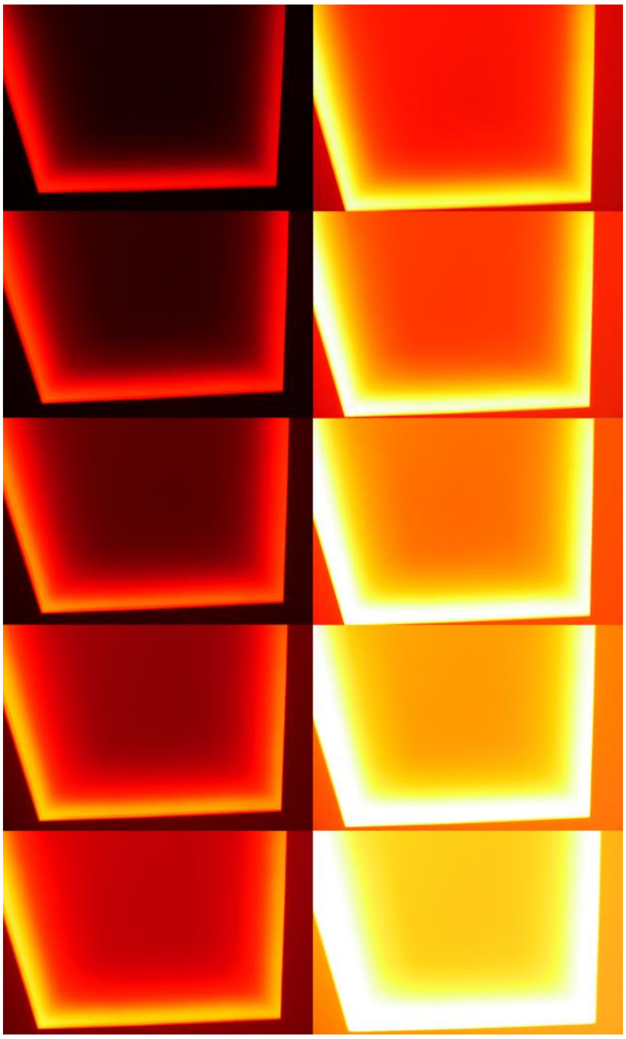

Figure 2. Time-varying spectrum and brightness according to dawn

B. *Hardware realization*

The sensor pair is on a prototype board due to experimental purposes, in order to find the right sensor type. The LED driver circuits are on stackable PCBs, with a base board [48]. One driver PCB contains three adjustable channels. Further channels can be added and used to the project in order to expand the LED strip segments or to increase the output power. The prototype circuit can be seen on Fig. 3.

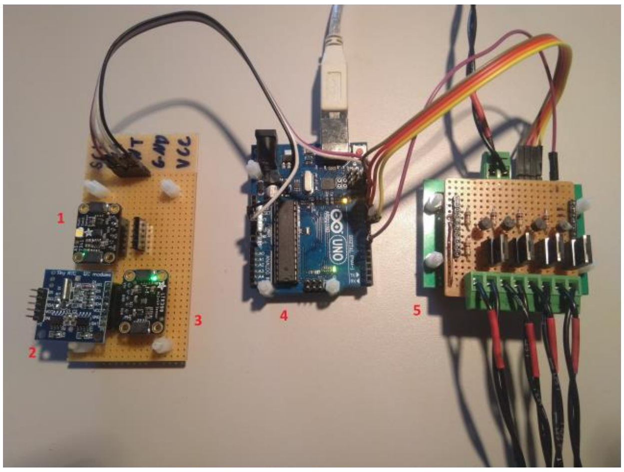

Figure 3. Experimental hardware implementation (1 – spectrum sensor, 2 – RTC, 3 – light sensor, 4 – microcontroller unit, 5 – LED driver module)

The brightness and spectrum sensor are connected to the microcontroller with I^2C bus. The sensors are accessible with 7-bit addressing. The light sensor is the LTR390.

The light spectrum measurement is made by the AS7341. The sensor is capable to measure light in 11 different channels, and 9 different wavelengths can be measured (415nm, 445nm, 480nm, 515nm, 555nm, 590nm, 630nm, 680nm and 910nm). It is equipped with 6 ACDs, so all channels can be read out close simultaneously using multiplexing.

A sunrise measurement graph can be seen in Fig. 4. The measurement points are made in every 10 seconds. The plotted results are containing the base values for the continuous spectral adjustment. The wavelength of the measurement channels taken into account is the value closest to the wavelength of the available LED light sources (see on Fig. 5).

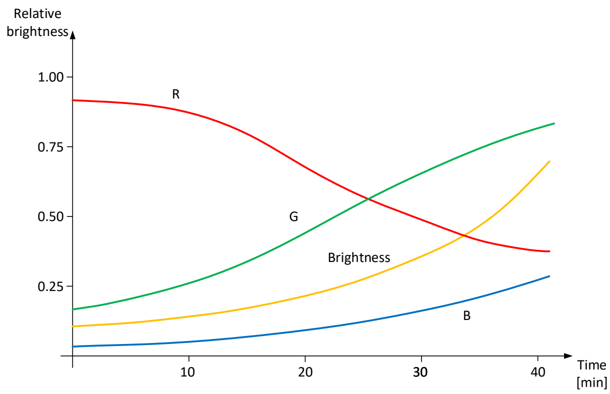

Figure 4. Dawn spectral change over time

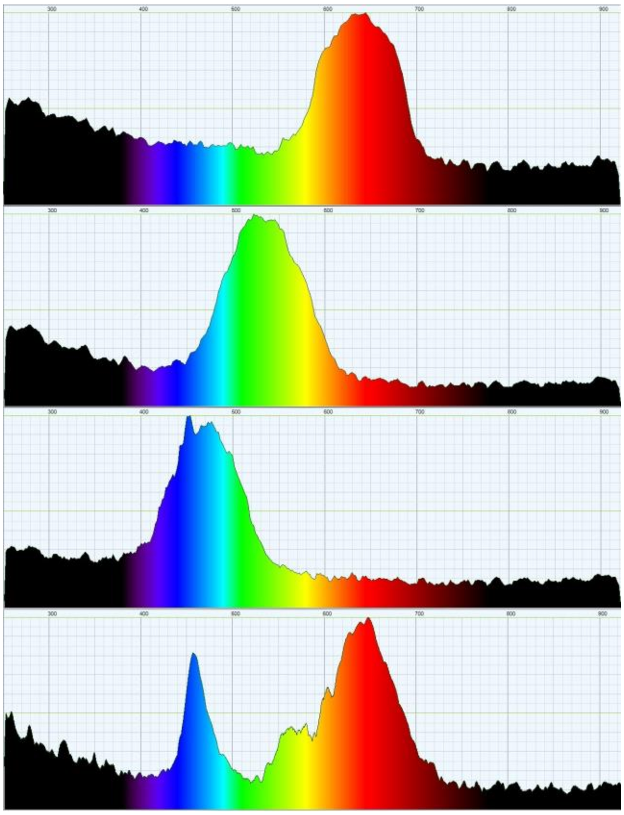

Figure 5. Spectrum of the light sources (top to bottom: red, green, blue white)

C. Software elements

The gradient spectral change is followed with software control. First starting with the red color, after that adding a green color to get orange kind of light. Next need to turn on the warm white channel, it also will add some blue to the spectrum. When the brightness is high enough, but there is lack on blue, blue channel is turned on. For further brightening first the warm white channel is increased, after that, blue light is added if necessary.

In every iteration, the brightness of the channels (the duty cycles of the drivers) need to be adjusted due to the sunrise spectral functions, to reach the gradient spectral change and for the continuous increase on brightness.

The sunrise spectrum is stored in a look-up table, one look-up table per channel, in the function of time, based on Fig. 4 and Fig. 5 data. The desired output value at a given point in time (between the stored data table points) is based on the interpolation calculation presented in the following article [49].

The alarm output is active and starting the alarm ringtone at the preset time. The dawn emulation is starting before the alarm time, and finishing till the alarm time. The dawn emulation flowchart can be seen on Fig. 6.

The possibility to adjust the LED brightness is quantized, the duty cycle can only be changed in finitely small steps. Fig. 7 shows the algorithm for fine-tuning the output.

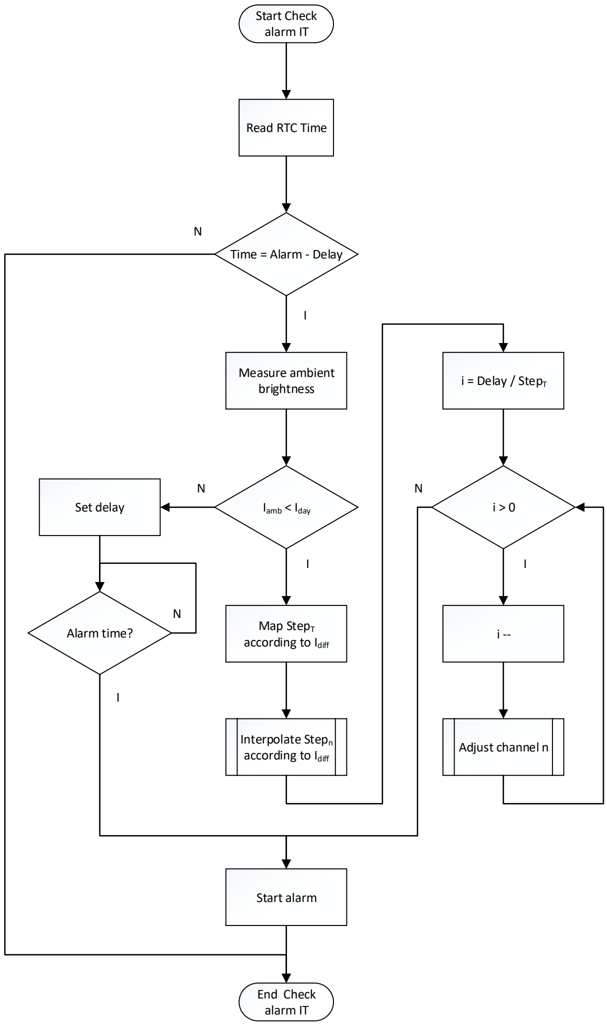

Figure 6. Alarm check with periodic output channel adjustment

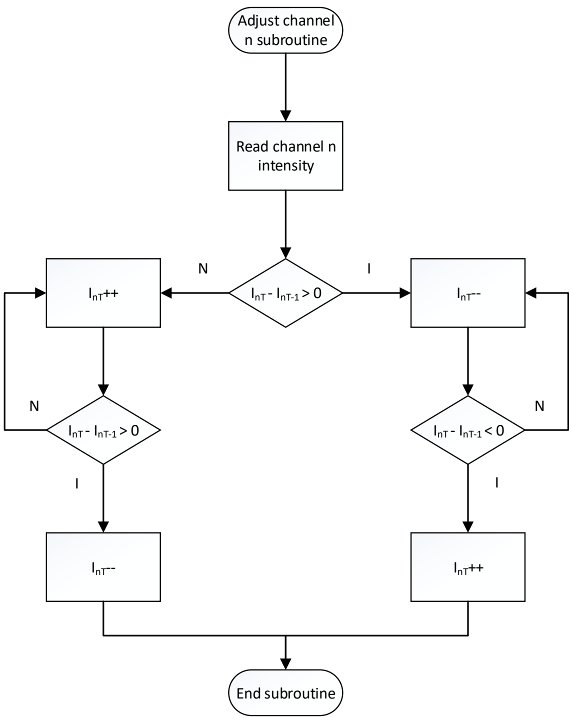

Figure 7. Flowchart of a unit-step approach procedure

IV. Conclusion

Plants and phototrophic bacteria convert light into chemical energy, which is distributed throughout the food web, feeding all heterotrophic organisms, including humans. Fossil fuel sources, the energy of part of the sunlight converted into biomass [50]. Sunlight not only transmits energy, but also information, in this respect the quality and quantity of light is crucial for living organisms, including humans [51, 52].

The primary goal of creating a wake-up environment recommended for people is to ensure an optimal spectral transition in the field of visual stimuli. A sufficient intensity, gradient dawn emulation helps to suppress the levels of melatonin, and this make the awakening person feel less tired, compared with an alarm clock beeping. The shown work uses a high quality measurement principle with cost-efficient sensor application, which can also be used well in various environments. The article deals with the theoretical background, the design considerations and a practical application, the hardware and software design are also included.

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