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Determination of Low-Cost Arduino Based Light Intensity Sensors Effectiveness for Agricultural Applications

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HIGHLIGHTS

- This research aimed to explore low-cost light sensors for agriculture.
- TSL2561, BH1750, TEMT6000, light sensors have been used.
- Low-cost light sensors can be used for a range of applications in agriculture.
- The light calculation values of low-cost light sensors were statistically compared.
- Calibration results were also analyzed, so the reliability of low-cost light sensors was calculated.

Abstract: This research is aimed to explore the efficacy and comparison of low-cost light sensor measurements for agricultural applications. For this reason, TSL2561, BH1750, and TEMT6000, low-cost light sensors have been used with various lighting regimes. Consequently, their efficiency has been tested for agricultural applications. These types of low-cost light sensors can be used in a range of applications in agriculture. For this reason, it is necessary to evaluate the calculation of light sources. The light calculation values of low-cost light sensors were statistically compared. Calibration results were also analyzed, so the reliability of low-cost light sensors was detected. Statistical analyses of light values have been presented in the results and discussion part of the paper as; the regression coefficient based on UNI-T UT382 vs. TSL2561 for the calibration was found as R-Sq 99,6%, R-Sq(adj) 99,5%, and S 10,18; for the calibration of UNI-T UT382 vs. BH1750 was found as R-Sq 100%, R-Sq(adj) 100% and S 2,73; at last for the calibration of UNI-T UT382 vs. TEMT6000 was found as R-Sq 99,2%, R-Sq(adj) 99,1% and S 14,71. After calibration, the regression coefficient based on UNI-T UT382 vs. TSL2561 for the light measurement was found as R-Sq 100%, R-Sq(adj) 100%, and S 2,21; the light measurement for UNI-T UT382 vs. BH1750 was found as R-Sq 100%, R-Sq(adj) 100% and S 1,09; also for the UNI-T UT382 vs. TEMT6000 was found as R-Sq 100%, R-Sq(adj) 100% and S 1,73. According to calibration and measurement results, the BH1750 sensor is better than the others.

Keywords: light analysis; low-cost light sensors; microcontroller; digital agriculture; agricultural production.

INTRODUCTION

Artificial lights are utilized in various areas of farming applications. Traditional agricultural light sources are generally studied in three parts; incandescent lamps, typically generate light energy by heating a tungsten filament to about 2500 ^{o}C; fluorescent lamps, produce light from the excitation of low-pressure mercury vapor during a mixture of inert gases and discharge lamps, don't use any fluorescent dust within the lamp glass, and elemental gases are heated to much higher vapor pressure and temperature [1] So, there are different types of lighting used in today's technology. Halogen lamps are simpler than incandescent lamps, but their costs are high. Fluorescent lamps are often linear or curved tubes or limited diameter bulbs. High-density discharge lamps include low-pressure sodium lamps, high-pressure sodium, mercury vapor, and metal halide.

Artificial lighting is required in several areas, but the general use of artificial lights in agriculture is to illuminate the growing products [2]. The strength, color, and length of the daily light that plants acquire affect photosynthesis and plant growth. It is the main limiting factor for greenhouse events during low natural light seasons. Additional lighting is necessary for the upkeep of vegetable development during the year. As a result, it can replace supplies at low latitudes during the winter season and make local vegetables valuable to the consumers. The positive effect of artificial lighting on different agricultural subjects like crop development, yield, or the effects on agricultural products like tomato [3], cucumber [4], and sweet pepper [5] has been extensively studied. Suggestions are given regarding photoperiod for various agricultural products. For example, the optimal cultivation yield of sweet peppers was determined at 14 and 20 hours of photoperiod. Also, the average weight of sweet pepper decreased at 125 µmol/m^2/s light regime compared to 75 µmol/m^2/h.s. The rise in lightning intensity is additionally alleged to end in an equivalent improvement in yield. Customarily, lights are placed over the cover, which ensures minimal illumination of the lower leaves [5]. Marcelis and coauthors in their research emphasized that a 1% improvement in light causes an increase of 0.7% in fruits and vegetables [6]. Both old and newer studies [7], [8], [9] indicate that lower leaves are often capable of being assimilated very actively. The benefits of inter-lighting, as against top lighting, are verified in various agricultural products. High red-light rates will promote fruit development when blue light is blamed for keeping the agricultural products compact and silky. For example, the blue light addition to the leaves improves the plant biomass and fruit production of cucumbers and tomatoes [10]. To investigate the effect of different artificial lights colors on wheat production, Goins and coauthors stated that they obtained the highest yield from wheat produced under white fluorescent lamps in the laboratory conditions [11]. They emphasized that wheat can be produced at the same biomass and yield like under white light using red and blue light, so the combination of red and blue light can change the continuous spectrum for plant production. Papadopoulos and Pararajasingham studied to emphasize the effect of plant variety on mild cutting in tomatoes. They stated that the optimal fruit yield will be achieved in a narrower area due to the increase in photosynthetic photon fluxes in greenhouse tomatoes. Also, they explain that in their studies performed illumination and enormous spacing improved the yield of tomatoes by increasing the dimensions and number of fruits. They concluded that the significant increase in yield was attributed to less overlap and shading of leaves, greater light penetration of leaves, less competition for light, water, nutrients, and fixation of CO_2. It's believed that the increase in plant density is often related to various lighting regimes. Changing plant or stem density can be a potential way to capture light and improve yields [12]. Lee and coauthors stated in their study with the Nano-TiO_2 photocatalytic method, activated carbon can effectively remove the phytotoxic substance accumulated in the nutrient solution and reduce the inhibition of lettuce growth [13]. They emphasized that it effectively removes toxic substances in the nutrient solution, increases the yield of plants, and reduces the content of Fe, Mn, and Zn in the plant. Also, Treder emphasized that spectral composition within the plant has an indirect effect on plant nutrition, so it's also important to work out the N supply of plants by evaluating the N uptake and therefore the intake and flow of fertilized water. Higher leaf transpiration at higher candlepower will contribute to higher nutrient content in leaves and possibly fruit. For instance, Treder found that when supplemental lighting is employed in air sections, there's a rather higher N, P, K, Ca, and Mg content [14]. The sunshine intensity also can affect the nutritional quality of plant parts. Winsor reported that the sugar content in the plant decreased with shading in another study [15]. Shibaeva and Markovskaya examined cucumber plants grown in growth chambers under high-pressure mercury lamps at different light intensities, photoperiod lengths, and plant ages, on the 14th day of the study, at all light intensities (60, 120, and 160 µmol m $^{-2}$ /s $^{-1}$) and found that leaves growing at 16 hours, 20 hours and 24 hours photoperiod lengths produce the same quantum [16]. At the same time, they imply that cucumber leaves at 120 and 160 µmol m^{-2}/s^{-1} had lower Fv / Fm (chlorophyll fluorescence measuring parameter) values under Continuous Light (CL) compared to 16 and 20 hr photoperiod at 21-28 days.

Continuous lighting has the following effects on plant groups: it prevents flowering and accelerates vegetative development in short-day plants, accelerates vegetative development and flowering in long-day plants, prevents flowering in mid-day plants, and generally lengthens stems in plants regardless of day length. If the light level is too low, it can harm bloom buds, development rate, internode length, windfall quality, and disease formation [18].

In addition to the general use of artificial lights in agriculture is to illuminate the growing products there are many other uses in agriculture like production area lightning. For example, lighting also can be utilized in animal shelters to supply light for livestock and poultry. Light fixtures should be precisely selected and placed to supply a suitable degree of lighting for every position and mission. The important light levels achieved during a given environment are highly influenced by the reflecting properties of walls and ceilings. Colors and textures should then be chosen appropriately. Lighting suppliers and construction experts may further minimize energy consumption by selecting suitable appliances, recommending wall, and ceiling finishes and providing arrangement designs for fixtures. Maintenance and repair operations aim to keep the light output from lamps and installations at optimum standards. The relevant maintenance features differ from service to operation. Recommended light levels for various agricultural facilities are shown in Table 1. In certain situations, lighting is often generated with natural light, thus eliminating the necessity for energy consumption within the supply of artificial light. Day-lighting strategies require the utilization of skylights, curtains, and reflective sidings [17].

Table 1. Optimum light levels for illumination [17]

Task	Foot-Candles
Free stall	15-20
Tie stall, barn, feed alley	15-20
Tie stall, center barn alley	20-53
General livestock housing	10
Holding area	10-20
Milking parlor- General	20
Operator's pit at the udder	50
Milk room	20
Manual wash sinks	100
Treatment or surgery area	100
Utility room	20
Office area (desktop)	50
Machine Storage	10
Farm shop- general repair areas	50
Exterior- Security	0.5-1.0
Exterior- Active areas	3-5
Poultry barns	20
Egg packing and inspection	100
Incubators, interior	50
Fruit and vegetable sorting	200-450
Storage and loading areas	20
Restroom	20

The purpose of this research is to stress that enhance the awareness of the lighting regime for farmers on the way to increase their production performance by adjusting the standard of electricity use in lighting with the help of effective low-cost light sensors and new technological applications. The integration of lighting into the manufacturing plan is an economic choice requiring increased expenses vs future returns. Higher candlepower and high illumination raise electricity costs. The query then emerges on whether the development within the expense of the lighting device is expressed in increased energy quality [18]. Low-cost light sensors give the chance to make correct, fast, and efficient light measurements. In this way, low-cost light sensors give the chance for the automation of lighting systems based on these measurements.

MATERIAL AND METHODS

Material

The need to utilize technology in agriculture, which has become much more popular with the industry 4.0 technology revolution, increases its importance day by day. There are not many low-cost color sensors in use and most professional sensors are very costly. Also, there are many different types of farm type sensors, some much more useful than others, some much more advanced than others. Therefore, we need to know the operational efficiency of these few low-cost color sensors for their application in agriculture and whether they are worth the investment. For this aim, TSL2561, BH1750, and TEMT6000, low-cost light sensors have been tested.

TSL2561

The TSL2561 brightness sensor is a light sensor that will be used under different light conditions (Figure 1). Compared to low-cost CdS cells, this sensor is more sensitive, allows the conversion of lux values, and may be configured for various gain/time ranges to work out ranges of sunshine values from 0.1 to 40,000+ Lux. This sensor contains both infrared and full spectrum diodes. Most of its sensors can only detect one or the opposite, and this is often not what the human eye sees.

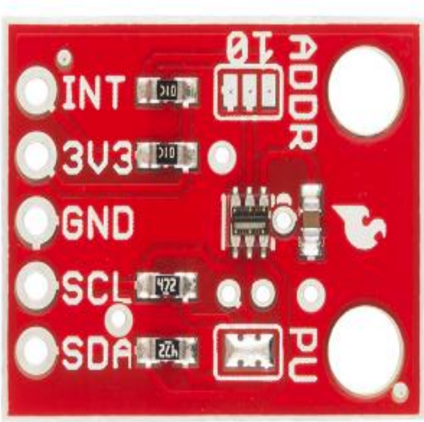

Figure 1. TSL2561 sensor

TSL2561 sensor features a digital interface. It has a special I2C address. The built-in ADC is often used with any microcontroller even without analog inputs. The spectral responsivity of the TSL2561 sensor can be seen in Figure 2. It’s suitable for the utilization of low-power data logging systems of about 0.5 mA when actively detected and fewer than 15 uA when in power-off mode [19].

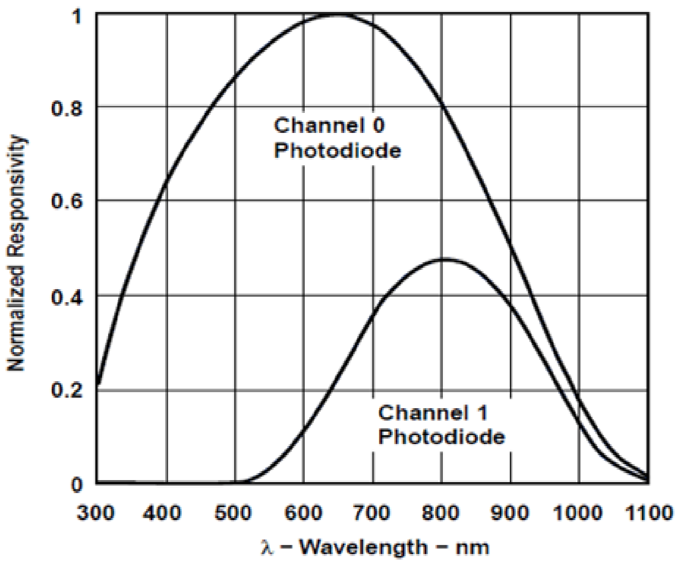

Figure 2. The spectral responsivity of the TSL2561 sensor [19]

Features of the TSL2561 sensor can be ordered as precisely brightness measurements under different lighting conditions, work on -30 to 80 ºC temperature scale, 0.1 to 40,000 lux in a dynamic scale measurement, work at 2.7-3.6V voltage scale and I2C interface [19].

Although useful for general purpose light sensing applications, the TSL2561 system is developed explicitly for different devices to increase battery life and offer optimal viewing during a range of lighting conditions. The backlight monitor, which may account for up to 30 to 40 percent of the entire platform capacity, is often operated automatically.

BH1750

The BH1750 sensor is the low-cost light sensor that can adjust the brightness of the different devices (Figure 3). The sensor uses the I2C communication protocol, making it more useful with microcontrollers. This device can directly give its luxury value. It operates between 2.4V-3.6V voltage range and consumes 0.12mA current. Although the results of the BH1750 sensor don't depend upon the sunshine source used, the effect of IR radiation is additionally significantly less [20]. The hardware of this device is simple. Its main constituent is BH1750. Since this device works with 3.3V module, a transformer is employed.

Figure 3. BH1750 sensor

Features of the BH1750 sensor can be ordered as it needs a 2.4V-3.6V power supply, works with 0.12mA low current consumption, measures1-65535 lux communicates with an I2C bus, it has +/-20% accuracy, little effect of IR radiation [20].

TEMT6000

Light sensors are widely used today, especially for automatic brightness at some devices or systems for adjusting exposure. The TEMT6000 sensor ambient light sensor detects its environment like the human eye does and is very similar to an LDR (light dependent resistance). This device can be described as a silicon NPN epitaxial planar phototransistor used to detect the visible light spectrum (Figure 4). TEMT6000 may be a silicon NPN epitaxial planar phototransistor during a miniature translucent mold for surface mounting on a computer circuit board. The unit is adaptive to the visible range of the spectrum. It's some features; suitable for human eye responsivity, large half-sensitivity angle Δ = ± 60°, SMD-style kit on PCB technology, ideal for IR reflow soldering, lead-free part, RoHS 2002/95/EC components and WEEE 2005/2006/EC components [21].

Figure 4. TEMT6000 sensor

Arduino UNO R3

Arduino UNO R3 is a board that use the ATmega328 microcontroller. It has 14 optical input and output pins thereon. 6 of them are often used for PWM outputs. Also, it has six analog inputs, a PC USB connection, an external power port, an ICSP header, and a push-button (Figure 5). Supports everything a user would like from a microcontroller; easily connects to a tool employing a USB cable. It also can be operated from an AC to a DC adapter or with a battery [22].

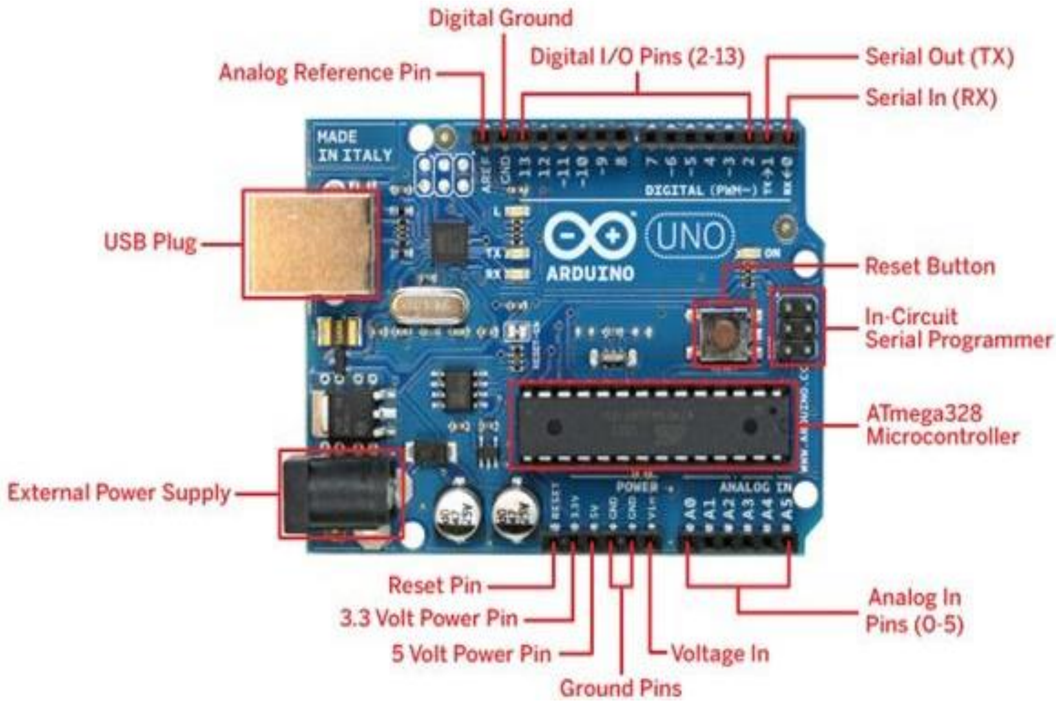

Figure 5. Arduino UNO R3 [22]

UNI-T UT382 Lux Meters

The UT382 model of the UNI-T is a 1999-count auto-range lux meter with a range of 20~20000 lux (FC). It has group data storage property and a USB interface (Figure 6).

Figure 6. UNI-T UT382 Lux meter

UT382 Lux meters measurements data can pass through Bluetooth to UNIT's mobile App (iENV) for further studies, storage, and export. Specifications of the UT382 Mini lux meter can be seen in Table 2.

Table 2. Specifications of UT382 lux meters [23]

Function	Range	Resolution	Accuracy Tolerance: ± (a %reading +b digits)
Illuminance measuring (lux)	20 lux	0.01lux	± (3% + 20)
	200 lux	0.1lux	± (3% + 8)
	2000 lux	1 lux	± (3% + 8)
	20000 lux	10 lux	± (3% + 8)
Illuminance measuring (FC)	2FC	0.001FC	The accuracy tolerance of FC can be verified by unit conversion: FC=10.76 lux
	20FC	0.01FC	
	200FC	0.1FC	
	2000FC	1 FC	

Method

Light is assumed to be a neighborhood of the spectrum that folks can see through the eyes. Because light may be a complex process, it cannot simply be calculated as air temperature or pressure. Each light has various properties. Light has a specific wavelength or combination of wavelengths to be determined, and these waves formed are expressed in hertz or cycles per second. The light features a unique power that can be calculated in a sort of alternative ways. There also are a couple of other functions like polarization [1].

For agricultural purposes, three light properties are usually measured:

- The irradiance-the sum of overall light energy falling on the surface
- Spectral quality-composition of wavelength and relative strength
- Duration-length of the traditional lighting cycle.

The variations of those three characteristics gives the sum of instantaneous and accumulated energy required for photosynthesis. In this research, the irradiance-the sum of overall light energy falling on the surface was measured by using low-cost light sensors with the support of Arduino UNO R3. The sensors' wiring diagram to the Arduino UNO R3 can be seen in Figure 7 which is used for this aim.

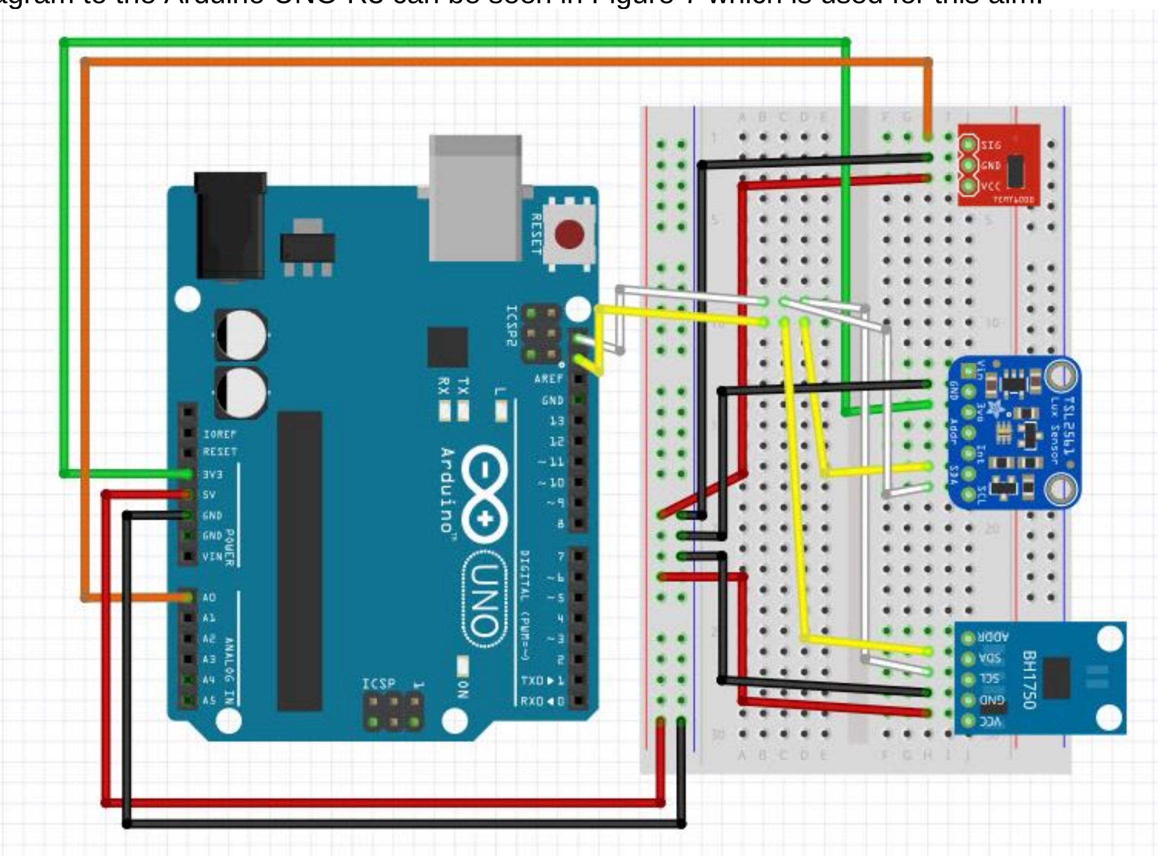

Figure 7. Wiring diagram of low-cost sensor connections with Arduino UNO

Before the measurements, first, the calibration process was done between sensors and a commercial Lux meter (UNI-T UT382) between 250-750 lux for each 50 lux,10 measurements were done for each light sensor for the calibration to increase with the help of regression equations in a dark room supported with a dimmable light source (Figure 8). A total of 30 measurements were done for the calibration of the low-cost light sensors. In this way, the low-cost light sensors were calibrated with the commercial Lux meter which is 10 times more expensive than these sensors. Then, between 250-750 lux for each of 50 lux, 20 measurements were done for each light sensor. A total of 60 measurements were done for detaching the measurement efficiency of the low-cost light sensors with the help of regression analysis.

Figure 8. Low-cost sensor measurements with Arduino UNO

RESULTS

The regression coefficient based on UNI-T UT382 vs. TSL2561 for the calibration was found as R-Sq 99,6%, R-Sq(adj) 99,5%, and S 10,18 seen in Figure 9. Also, the regression coefficient based on UNI-T UT382 vs. BH1750 for the calibration was found as R-Sq 100%, R-Sq(adj) 100%, and S 2,73 seen in Figure 10. Additionally, the regression coefficient based on UNI-T UT382 vs. TEMT6000 for the calibration was found as R-Sq 99,2%, R-Sq(adj) 99,1%, and S 14,71 seen in Figure 11. The maximum error was calculated as 0,8% at the TEMT6000 sensor among all low-cost light sensors based on regression analysis. All calibration equations for each sensor are also present in Figures 9-11. The best calibration result was found at the BH1750 light sensor between all low-cost light sensors. It means that BH1750 low-cost light sensor measurements are closer to the commercial light sensor measurements. So, this means that it is better than the other sensors for the low-cost and optimum usage in agricultural plant production and in specific production areas.

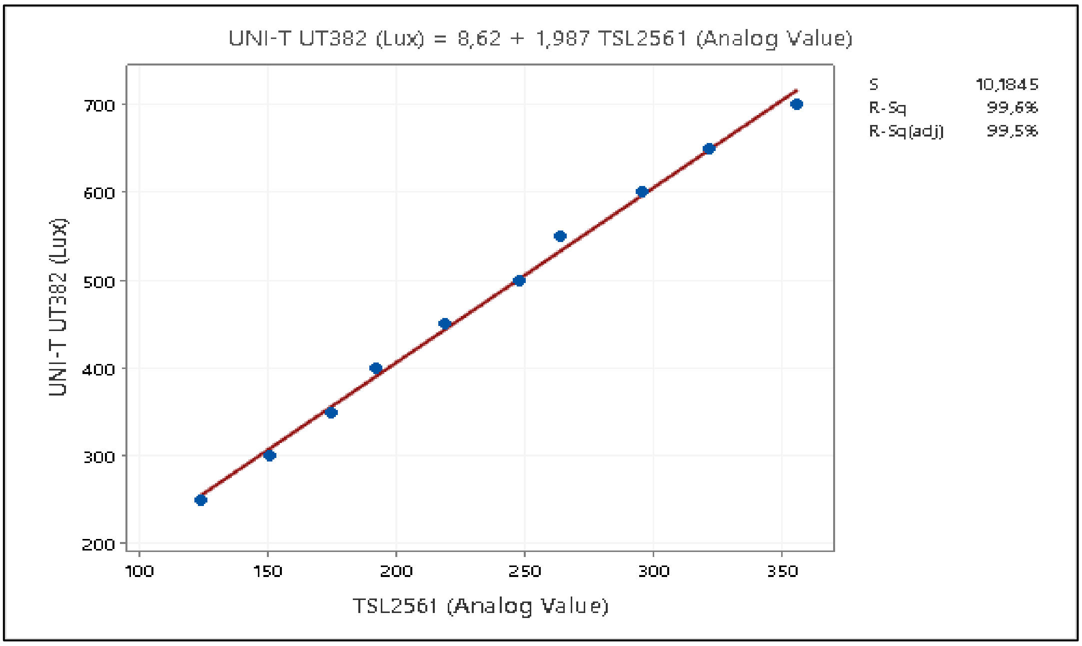

Figure 9. Regression equation and coefficient based on UNI-T UT382 vs. TSL2561 for the calibration

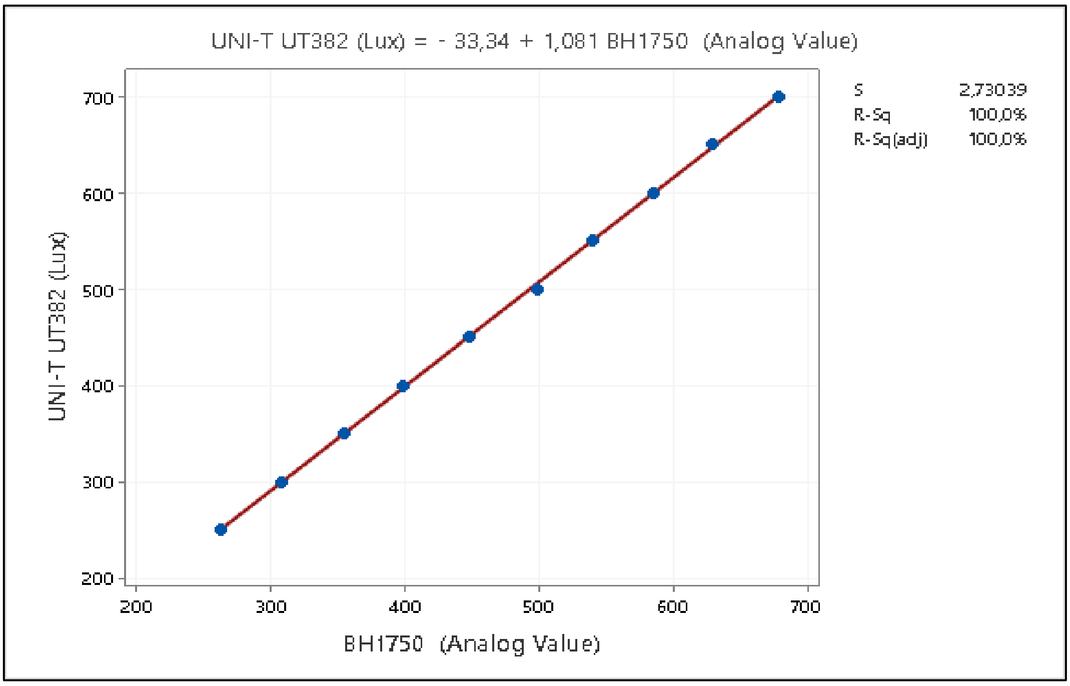

Figure 10. Regression equation and coefficient based on UNI-T UT382 vs.BH1750 for the calibration

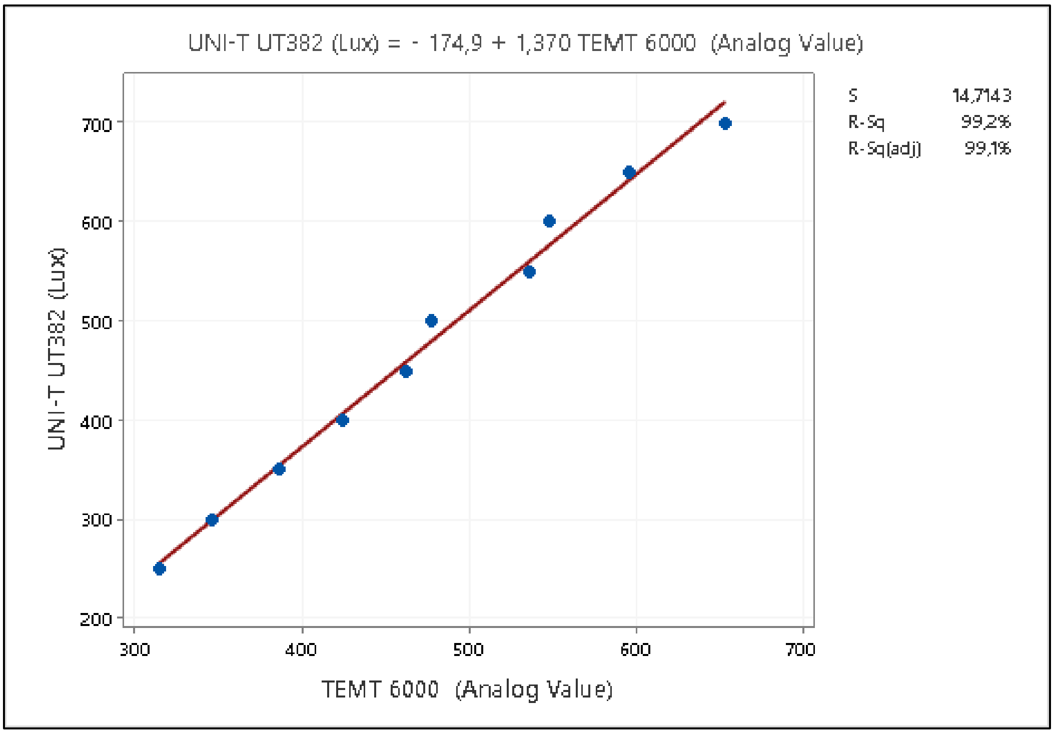

Figure 11. Regression equation and coefficient based on UNI-T UT382 vs. TEMT6000 for the calibration

After the calibration process, the light measurement process was done between sensors and the commercial lux meter (UNI-T UT382) with the help of regression equations. The regression coefficient based on UNI-T UT382 vs. TSL2561 for the light measurement was found as R-Sq 100%, R-Sq(adj) 100%, and S 2,21 seen in Figure 12. Also, the regression coefficient based on UNI-T UT382 vs. BH1750 for the light measurement was found as R-Sq 100%, R-Sq(adj) 100%, and S 1,09 seen in Figure 13. Additionally, the regression coefficient based on UNI-T UT382 vs. TEMT6000 for the light measurement was found as R-Sq 100%, R-Sq(adj) 100%, and S 1,73 seen in Figure 14.

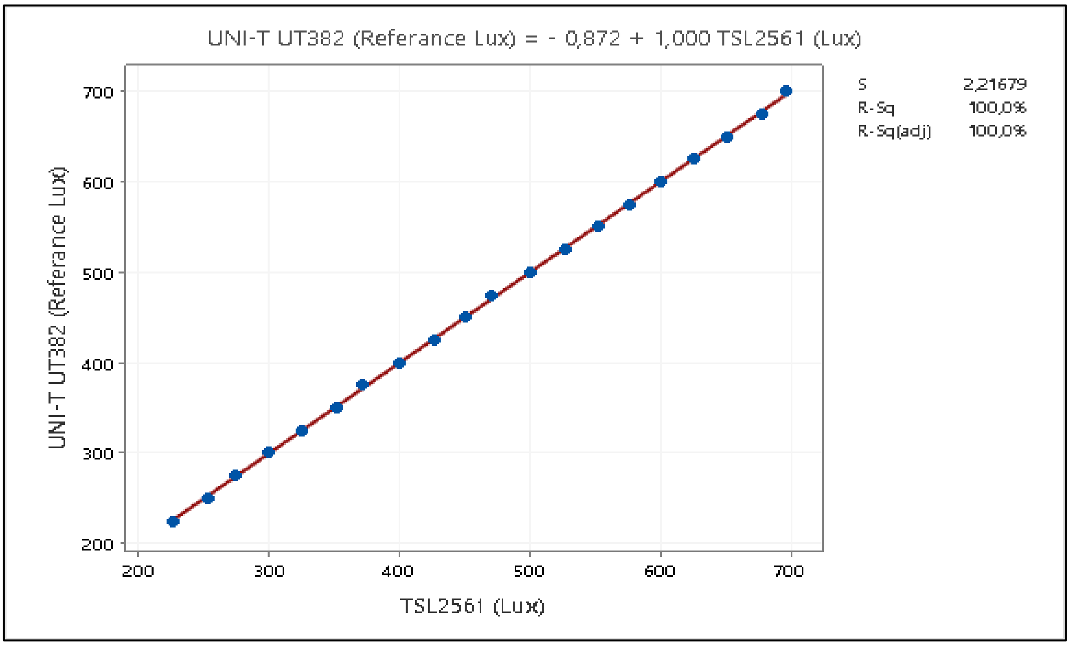

Figure 12. Regression equation and coefficient based on UNI-T UT382 vs. TSL2561for the measurement

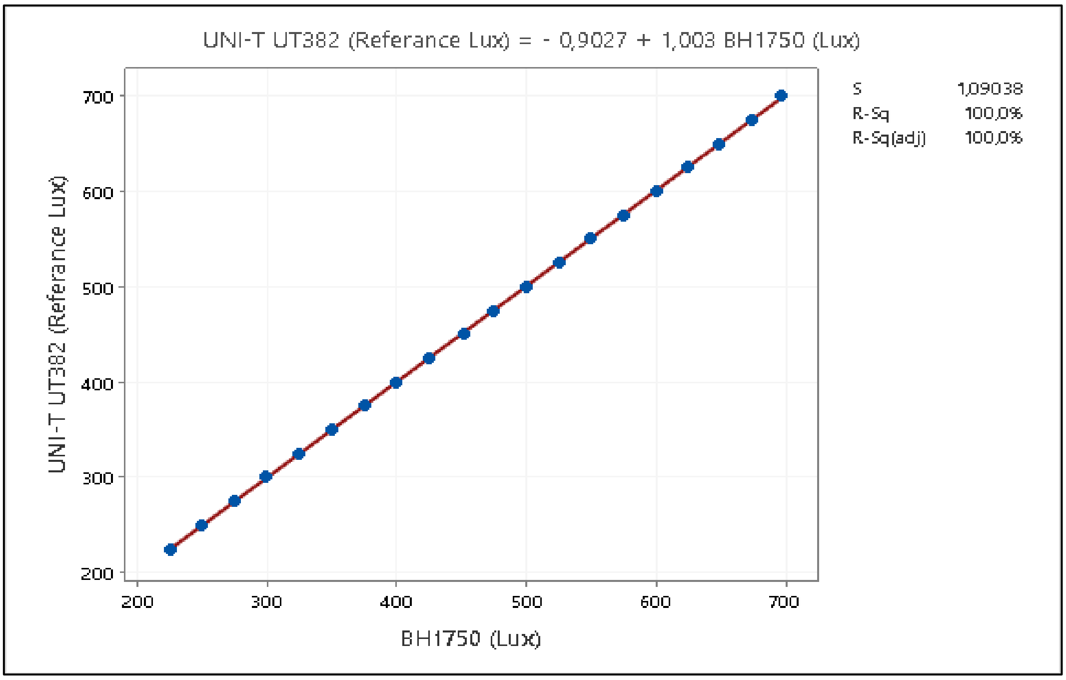

Figure 13. Regression equation and coefficient based on UNI-T UT382 vs. BH1750 for the measurement

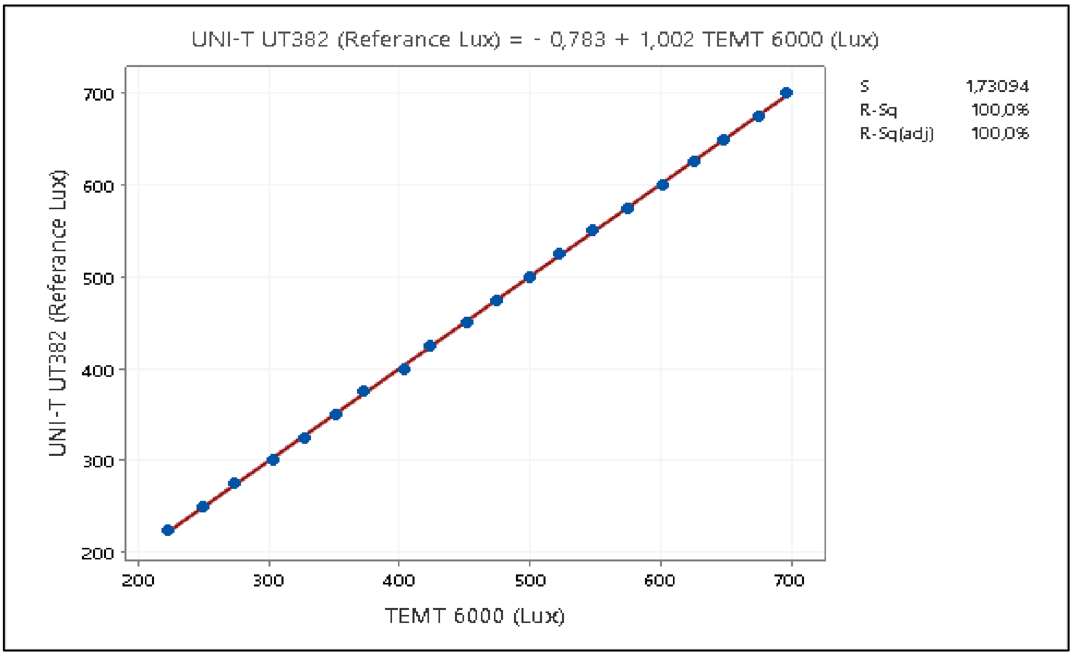

Figure 14. Regression equation and coefficient based on UNI-T UT382 vs. TEMT6000 the measurement.

As result, it is seen that from Figures 12-14, the low-cost light sensors and Arduino-based measurement unit can be successfully use for the agricultural light measurements applications. There is no difference between the results of the low-cost light sensors when we compare each other after the calibration process. All of them have 100% regression with the commercial light measurement device light values.

DISCUSSION

Related to the research subject, in the literature, Hrbac and coauthors tried to measure the optical parameters of industrial light intensity low-cost MAX44009, TSL2561, and BPW21 industrial light sensors in their research [24]. They stress that the MAX44009 ambient light sensor is superior to the TSL2561 brightness sensor in terms of the wide light measurement range between 0.045 lux to 188,000 lux concerning spectral characteristics of sensors using the specified light sources, the lowest error is achieved by the

TSL2561 integrated sensor, while the highest error is indicated by the BPW21 photodiode. In addition, they imply that the TSL2561 sensor's largest positive deviation is 15% (LED lights) and the largest negative deviation - is 3% (Osram NAV – T 70W sodium lamp), and BPW21 photodiode is 50% for all types of light sources selected except incandescent lamp. Carpenter stated in another study that the light intensity of the TSL2561 sensor has a significant reaction range and is not as strong as the TSL2591 and that the lux sensor has the highest sensitivity compared to other sensors used in the research. They stressed that the TSL2561 sensor responds quickly to light changes and that the default device configuration for TSL2591 will not match because it cuts sample rates in 0,001 seconds [25]. In another study, Zagade and Kawitkar designed a wireless monitoring system consisting of an SHT71 temperature humidity multi-sensor module and a TSL2561 ambient light sensor, which can measure different environmental parameters in series in a greenhouse environment and act as a CPU to monitor environmental variables [26]. Addition to the literature, in our research, we focused on TSL2561, BH1750, and TEMT6000 low-cost light sensors. We found that after calibration the low-cost light sensor responses are the same, but we also found that according to calibration and measurement results from BH1750 sensor is measuring light values in different light regimes better than the others. Between the comparison of the low-cost light sensors, the calibration formulas, which are also regression equations, were presented in Figures 9-11 to make easy and efficient automation applications by using these low-cost light sensor modules in the market.

In addition to the comparison of the low-cost light sensors in the literature, on the usage areas and possibilities of light measurement Bńlský and coauthors concentrated on the usage of the Arduino platform for light field analysis. They stated that small computers such as the Arduino UNO and Arduino Micro are generally appropriate for use in modeling photometric devices, such as the goniophotometer model, or the development of simple approximation measuring instruments [27]. Kilari and coauthors investigated automatic light intensity control using Arduino UNO and LDR. They emphasize that, under the overall intensity of the room, the Arduino voltage can be set to a value capable of driving some higher loads of lightning energy [28]. Kulkarni and coauthors used the Arduino Uno Atmega328 to measure light luminance and temperature for real-time energy-saving applications. They emphasized the significance of developing an effective multipurpose light monitoring system that aids in the automation of real-time applications [29]. Putjaika and coauthors focused on a control system in intelligent farming by using Arduino technology and they used real light intensity measurement for watering plants [30]. So, these literatures shows that the Arduino UNO R3 board which is used in our research is useful and low-cost board for the monitoring light regimes.

CONCLUSION

Farmers generally use visual information to make decisions about plants. But to get scientifical plant output and optimize critical to assess plants and reactions, sensors usage makes it better and the sensor data can be for plant control. This is the technique that you can communicate with plants, also it is a type of approach that use environmental conditions as input and plant reactions as output. It mainly refers to the use of sensors to measure the response of plants. This strategy is critical for monitoring the responses of the plants to environmental conditions. In this way, the problem identification and optimization can be done for complicated and unpredictable conditions that are difficult to accurately explain. However, smart control approaches take decisions significantly easier in these conditions.

Additionally, energy conservation is currently being discussed on all platforms. The technical measures are taken, however, are insufficient to address the energy crisis. Automation that results in energy savings is very important and critical in real-time applications like production area and streetlight control also, maintenance on the farmland between the production areas and buildings. Automatic light intensity control using Arduino UNO and low-cost light sensors has been implemented in agricultural areas to reduce power consumption and eye strain. In addition to the usage of the low-cost light sensor support, daily cleaning, optimized operating techniques, and the implementation of reliable lighting installations; wiring, and control systems will reduce the usage of electricity for lighting. Using focused reflectors to shed light on the areas of concern, using occupancy sensors, motion detectors, photocells, half-night alarms, timers, and other monitoring systems to keep the lights on when needed. Installation of control devices to illuminate just certain places where lights are required, introduce a routine schedule to repair and preserve lighting fixtures. Using the recommended published illumination levels to courage further lighting is important, for greenhouse illumination, utilizing fixtures made especially for greenhouse use at the specified height of mounting. Fitting lighting activity with plant requirements, allowing the utilization of sophisticated control techniques wherever feasible. Also, start-up times and lighting cycles can minimize costs by avoiding high demand charges. Furthermore, the "Internet of Things" (IoT) is a technology that enables objects to communicate and connect.

In both industry and agriculture, this will result in more efficient patterns and processes. Before the place of lightning, some lightning simulation software is used by lightning experts, but they are not enough to control real-life conditions. Also, after the calibration process, these low-cost light sensors can be used as trusted measurement devices.

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