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The Application of Photoconductive Bacteriostatic Infrared-LED for footwear in Environmental Art Installation

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ABSTRACT

Background: With an increase in the trend of using high-tech for renewable energy, the storage and conversion of solar energy become increasingly popular. Rather than getting high benefits of electricity, other important issues are how to bring the considerate service and pleasures for the daily home life. The popularization and application of modern materials and creative beauty of demand by design were integrated with each other. **Objective:** This project combines different research fields of architecture and environments art, and optoelectronics technology to develop a trans-boundary new product. We proposed an apparatus to improve the hygiene of internal space of footwear and apply the green technology in daily life; moreover, the designs of the apparatus were also demonstrated beautiful fashion whether in day or night, and coordinate with the environment each other. The origin concept the art installations was form the most well-known of "photosynthesis" in the nature, completing the absorbing carbon dioxide and releasing oxygen in a cycle by a tree itself. **Results:** The shoes can hang on branches of this tree; leaves were modified by soft solar panel to absorb solar energy; the use of dual-wavelength infrared-LED design plays a role in sanitation of the shoes; and the part of flowerpot is the base of solar energy storage and control unit. The figure of the apparatus was bionics based on a plant to show the elegance. **Conclusion:** In the future, the installation will move towards the development of design integration with balcony, in order to form the shoes combined with solar collector panels, providing three-dimensional green day automatic irrigation system with night scene mural shiny facade. In order to reduce costs to achieve commercialization of new environmental art being provided

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INTRODUCTION

Moist and hot climatic conditions are a hotbed of mold bacteria in shoes, and socks. Exposing shoes to the sun can effectively kill the bacteria; however, the busy urban life makes it difficult to do so. This study proposed a design of a bionic tree using solar power technology.

The idea for this art installation is based on photosynthesis process. The branches of this tree can be used to hang shoes, and the leaves are flex boards that absorb solar energy. The shoe drying rack device is designed using Arduino to control a dual wavelength infrared-LED. The pot is the base for storing and converting solar energy.

The device is designed in the form of a tree, thus having the features of aesthetically pleasing, improving shoe hygiene with a bacteriostatic and deodorizing device, realizing green energy, and bringing art installation into daily use.

Design Concept And Experimental Principles:

Design concept:

The design concept for the proposed photoconductive bacteriostatic device (Figure 1) was formed after numerous rounds of brainstorming, during which a number of designs and possibilities were discussed.

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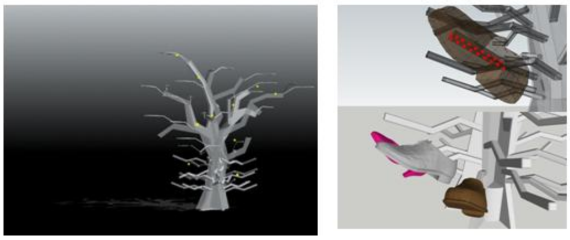

Fig. 1: Original design concepts of the photoconductive bacteriostatic device.

The tree shape was chosen as it has the optimal solar absorptivity, near-infrared LED bacteriostatic effect, and the overall aesthetic value. After making a number of tree models and analyzing their advantages and disadvantages, this study chose the tropical broad leaf tree as the prototype tree shape because it has large leaves to hold enough solar panels. (Figure 2)

Fig. 2: After making a number of tree models and consideration, an optimal model was chosen.

Near- Infrared bacteriostatic principle and experimental design:

Recent studies found that the 870nm and 930nm infrared light waves have an inhibitory effect on the growth of fungi and bacteria. The 870nm infrared light is absorbed by the cytochrome C inside the cells. When the light intensity is low, the structure and function of the Cu-A and Cu-B chromophores of cytochrome C are changed after illumination. The oxidation-reduction characteristic is changed, thus promoting the transfer of electrons, accelerating the intra-cellular NAD^+/NADH synthesis, and increasing the ATP resultant quantity. The intra-cellular oxidation-reduction state change will also activate the transcription factors (NF-kB, AP-l), so as to enhance the cell replicability. However, when the cells receive high energy and high dose illumination, intra-cellular light absorbing molecules such as porphyrin and flavoprotein will turn into photoactive substances, thus generating a photodynamic effect and inhibiting the synthesis of deoxyribonucleic acid or ribonucleic acid (DNA), all of which influence the reproduction and growth of bacteria.The 930nm infrared light wave is absorbed by the C-H covalent bond of the long chain fatty acids in the cell membrane or mitochondria membrane. If the 870nm infrared light is emitted, the electron transport chain of the bacteria for maintaining the proton gradient inside and outside the cells will become disordered. Consequently, the electrons on the cell membrane will not be transported and the oxygen consumption will stop. Meanwhile, the synthesis of adenosine tri-phosphate will also stop. Adenosine tri-phosphate is the direct energy source for the vital activity of bacteria; once the mechanism's energy source is inhibited, the growth, reproduction and division of bacteria will be influenced significantly (Eric Bornstein, *et al*., 2009; Eric Bornstein, *et al*., 2010; Adam, S., *et al*., 2012).

Development Of The Prototype:

1:2 model prototype:

The 1:2 scaled model was made in a laboratory before the 1:1 prototype was produced. The material and overall structural stability were taken into consideration. The fabrication process is shown in Figure 3. The materials included acrylic sheets, aluminum tubes, wood boards, Infrared-LEDs, conductors, and solar panels.

1. The aluminum tube was cut using an abrasive-disk cutter to the appropriate length and then heated for bending.
2. The acrylic sheet was cut into a leaf shape using a laser cutter.
3. The Infrared-LED shoe drying rack was assembled and wired.
4. The solar panel was assembled to the acrylic leaf and wired.
5. The aluminum tubes were drilled and wired, and the bent aluminum tubes were fixed.

6. The base consisted of wood board and putty and contained space for an accumulator.

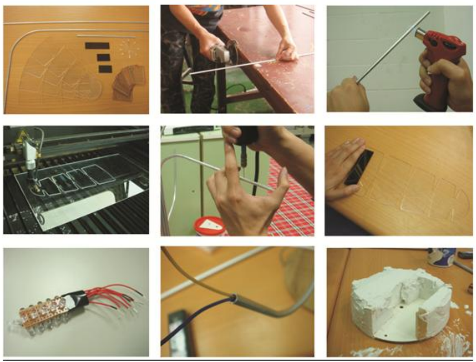

Fig. 3: 1:2 scaled model implementation process.

A total of four pairs of shoes could be placed on the tree at one time, as shown in the top view of Figure 4.

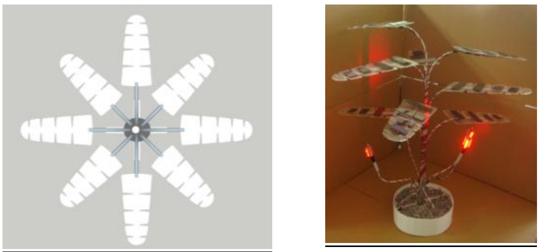

Fig. 4: Top view of leaf distribution and 1:2 model tree.

The implementation method for the 1:1 prototype:

To select the appropriate tree shape, this study considered the factors of the number of solar panels, materials, and dimensions. Finally, the tropical broad leaf tree was chosen as the basic prototype. The design was divided into the upper (leaves), middle (shoe drying rack) and lower (base) parts. The detailed descriptions are shown in Figure 5.

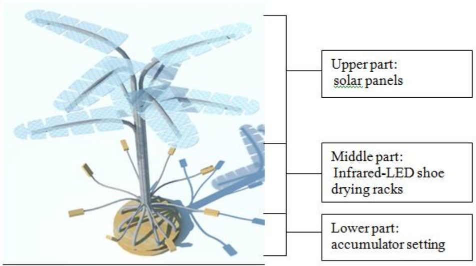

Fig. 5: Structural division of the tree design.

1) Upper part: solar panels:

Based on the concept of green technology, the leaves were designed to place solar panels. The model of the solar panels was SM1515, and each panel could generate 7.5V of 130mA power. Each leaf surface could hold four SM1515 solar panels, of which two were in a series connection and two were in a parallel_connection. The total power supply was 15V 260mA for the bacteriostatic operation of one shoe. Each leaf was 60cm long and 25cm wide and was cut using a laser, as shown in Figure 6. There were four SM1515 solar panels (14.5cm long and 6cm wide) mounted on each leaf. The configuration is shown in Figure 7.

2) Middle part: Infrared-LED shoe drying racks:

The Infrared-LED bacteriostatic device was made based on the infrared bacteriostasis proposed in recent research. UV-light was not used because it is harmful to human body, and requires a confined space for use. Thus, bacteriostasis can be performed on various types of shoes, including sandals and open-toed shoes. Even when not use, The proposed device can be used as a decoration. The circuit inside the shoe drying device is shown in Figure 8. Each shoe drying device has 30 Infrared-LEDs with wavelengths of either 870 or 930. The optimal bacteriostatic effect would be reached after 6~10 h of irradiation. Figure 9 shows the preliminarily implemented device.

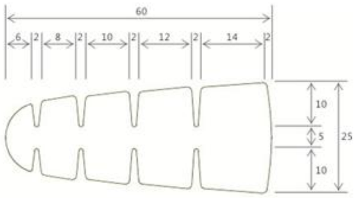

Fig. 6: Leaf dimensions.

Fig. 7: Solar panel configuration.

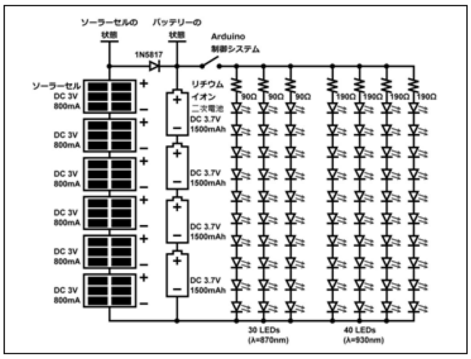

Fig. 8: Infrared-LED shoe rack circuit design.

Fig. 9: Infrared-LED shoe drying rack device and accumulator setting base.

3) Lower part: accumulator setting:

The base of the tree was designed to accommodate the accumulator used to store the electric power generated by the solar panels. The lithium batteries were the 18650 model and there were four in a series connection, supplying a total of 14.8V 2600mA power. The aluminum tubes forming the tree were bent outwards in eight directions equally from the bottom, so that the tree would be balanced naturally. They were embedded in the base wood board through eight holes, as shown in Figure 10.

expertimental test of the bacteriostatic effect:

1) Infrared-LED experimental setup:

The optical radiation intensity of both LED wavelengths (shown in Table 1) was 20mW. The divergence angle after packaging was 20°. Considering the space inside shoes, the maximum distance between the LED and the irradiated surface was set as 3 cm. The irradiation time was set to at least 10 hours, which was the expected time period that people would be staying at home. The optical radiation characteristics of the system are shown in Table 2.

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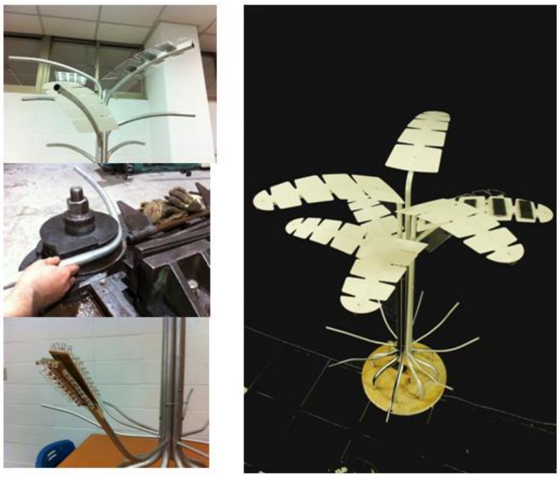

Fig. 10: Infrared-LED shoe drying rack, solar panel and main body of aluminum tubes.

Table 1: Specification characteristics of the Infrared-LED used in this study.

Middle wavelength	870nm	930nm
FWHM	40nm	50nm
Half vision angle	10°(±2°)	10°(±2°)
Forward optical power	8.3mW	6.5 mW
Total optical power	22mW	20mW
Upgrade(decline) time	15(10)ns	1(0.5) μs

Table 2: Optical radiation characteristics.

Ouput power	Single LED Illumination area	Irradiation time	Total energy	Energy density	Power density
20 mW	0.87cm^2	28800sec(10hr)	7200J	8200J/ cm^2	285mW/ cm^2

In order to increase the irradiated area and optical radiation quantity, the near- infrared LEDs were used to form an area source for irradiation. The area source consisted of 18 packaged 870nm and 940nm LEDs with a diameter of 5mm. The LEDs were arrayed at intervals of 1cm, so as to ensure that the irradiated area was uniform while enlarging the irradiated area. A total of 36 LEDs were welded on a 12cm×12cm print wire board and then sealed for waterproofing. The constructed area source is shown in Figure 11.

2) Experimental samples for bacteriostasis:

In order to prove the dual wavelength LED optical radiation device could influence the growth rate of bacteria, a *colibacillus* was used to observe the light application time and growth rate. The experimental conditions are listed below:

A. Experimental material and method of colibacillus K-12:

The *colibacillus* K12 liquid medium was grown in a Luria Bertani broth (LB) culture medium (25g/l). The culture dish contained 35ml of the LB culture medium (25g/l LB, 15g/l agar plate medium). The culture medium was diluted with phosphate buffered saline (PBS). The above procedures were carried out using aseptic techniques.

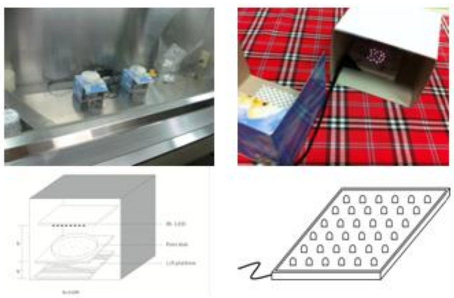

Fig. 11: Infrared-LED unit design and experimental observation.

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B. Bacterial growth kinetics:

Multiple 50ml LB cultures derived from a seed culture medium were inoculated and grown at 37°C. A fresh culture medium was selected on the second day, and 5% was inoculated at 37°C to 50ml LB. The O.D.600 value was monitored and measured at intervals of 30 to 45 min until the culture entered into the stationary phase.

C. Original breed production:

The logarithmic phase culture CO.D.600 was 0.75. Then, 10mL of the culture was placed at 40°C, mixed with 10ml 50% glycerol. It was separately loaded into 20 eppendorf tubes, and quickly frozen in liquid nitrogen. The eppendorf tubes were stored at -80°C.

D. Liquid culture:

The procedures were the same as the liquid *colibacillus* K12 culture. A total of 100μl of the subculture was taken out and diluted continuously in PBS to a ratio of 1:1200. The diluent was cultured at room temperature for 2 h, or O.D.600 stopped increasing, so as to ensure that the bacteria in the PBS suspension reached a static state without significant growth. A relatively stable quantity of bacteria was extracted for further testing.

Once the K-12 diluent was confirmed as being in a static state, 2ml of the suspension was absorbed and placed into 24 tissue culture dishes. Under the given optical radiation parameter, 200ml of the selected final diluent was coated on three separate culture dishes. The culture dishes were cultured at 37°C for 12 h using near infrared. Afterwards, the colonies were counted and recorded manually, and the growth of various culture dishes was photographed.

3) Experimental result of Infrared-LED bacteriostasis:

The current technology can use photothermy (heat) to kill bacteria; however, the temperature of the area containing bacteria will rise significantly for a certain amount of time. In order to minimize the effect of photothermy, this study placed the near- infrared LED module at 6 cm away from the bacterial culture dish, and ensured that the temperature of this position was equivalent to the ambient temperature. The bacteria were cultured at a constant temperature of 37°C and irradiated with infrared light. In addition, in order to validate the bacterial growth at room temperature (15-20°C), this study put the bacteria in a sterile operating console to observe the growth of bacteria irradiated with 7200J dual wavelength LED optical radiation at the two temperature ranges, respectively. The experimental results are shown in Figure 12.

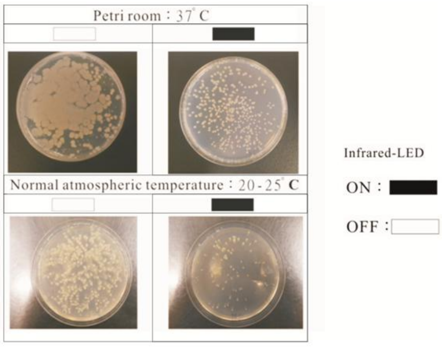

Fig. 12: Bacterial growth at different temperatures.

Figure 12 shows that at a constant temperature of 37°C, the bacteria grow very fast in the culture dish that had not been irradiated with dual wavelength near infrared light, and the colonies overlapped after 24 h. However, the bacterial growth rate decreased obviously in the culture dish irradiated with dual wavelength near infrared light. The same situation occurred in the culture dish at room temperature, in which the culture dish irradiated with dual wavelength near infrared light showed little bacterial growth. The experimental data proved that the sample irradiated with dual wavelength near infrared light had the optical antibacterial effect, thus proving the antibacterial mechanism of this device.

Conclusion And Suggestions:

Solar energy has become a popular green energy. When seeking benefits in electricity effectiveness, integrating the aesthetic design with the technological innovation can bring convenience and fun to daily life. The proposed design is an example that combines architecture, landscape, technology, art, and photovoltaic domains.

The experiment confirmed the bacteriostatic effect resulted from short-distance irradiation of infrared light in two wavelengths. In comparison to UV-light, infrared light is not harmful to the human body, its faint glow

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can be used as a decoration, and it has the bacteriostatic effect. It may become a trend to use infrared light to replace UV-light for bacteriostasis, thus protecting the health of users, prolonging the durability of shoes, and adding aesthetic values.

Although solar energy is an environmentally-friendly and convenient source of green energy, its conversion efficiency is limited, and there must be an adequate exposure area to generate a stable power supply. In order to meet the requirement of green energy, the leaf surface of the tree needed to be large enough to hold solar, thus making the total volume of the tree as large as the an adult. However, as urban living spaces are mostly function-based small spaces, an appropriate location for the tree at home became a problem. Therefore, the device should be integrated with the balcony area in the future. Our future study will focus on combining the shoe cabinet on the balcony with solar panels. The proposed system can serve as an automatic irrigation during daytime, and a flashing façade painting at nighttime, thus reducing the cost of commercialization and providing environmental art.

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