Spectroscopic investigation of transparent polylactic acid

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Abstract. In the recent years, the 3D printing technology became more affordable, being used in various fields like medicine, design, architecture, manufacturing and electronics. Using 3D printed materials has many advantages: speed, cost, design freedom, customization and sustainability. An application in which 3D printing can be used is Visible Light Communication (VLC), where the polylactic acid (PLA) material can be used as cover for the transmitter (which is typically a LED), or the receiver, in order to protect the system from various external factors. The paper investigates how transparent PLA material with various thicknesses attenuates and influences the spectral composition of the light passing through it. The reflectance spectrum is measured using a spectrometer, and the attenuation using a light meter. Based on the results, it can be determined if PLA can be used in a certain optical application, depending on the spectral composition of the involved light.

1. Introduction

3D printing can be considered an economic gamechanger. In the starting years of this technology, its high price made it untouchable by the masses. Nowadays the cost of the most popular 3D printers, the ones that are based on Fused Deposition Modelling (FDM) [1] decreased to the point that startups or individuals can afford them without needing a funding. For developing and bringing to market a hardware device, the most expensive part, in general, is the housing, which is usually made from plastic. Manufacturing custom made housings is very expensive because of the necessity of building a custom mold that would be used to produce the cases through plastic injection. Many low budget companies struggle with this aspect when trying to manufacture a hardware product. The 3D printing [2] technology comes to solve this issue, allowing easy and cost-effective prototyping [3] of the plastic housings for hardware systems. The diversity of raw materials that are used in 3D printing is very large, but the most popular remains the PLA (polylactic acid) [4]. Interesting versions of this material were developed, like conductive PLA which could be used in manufacturing prototypes of electrical circuits, or for ESD (electrostatic discharge) protection [5]. Another uncommon category of this material is the transparent PLA. Depending on its the optical properties, this material could be used to reduce the costs of prototyping protection enclosures for systems that involve the use of light sources. The protection methods that are used nowadays, based on polymethyl methacrylate (PMMA), commonly known as plexiglass, are cost effective, but their laminated raw form may not be suited for any design, and their processing is still expensive.
The VLC system [6] is a communication that is based on the visible spectrum. The communication uses LEDs [7] as the transmitter and photodetectors [8] or image sensors [9] as the receiver [10]. The data is transferred by changing very fast the light intensity of the LED, the human eye not perceiving this change as flicker. The VLC communication can be used in various applications: in aviation, providing media services for the passengers, in indoor localization systems, tracking an moving object in real-time [11], in smart displaying signboards, displaying information about various timetable of public transportation system, and in the automotive field [12] in the Intelligent Transport System (ITS) [13] applications. For example, the ITS system can be used in case of traffic congestion in order to adjust the traffic lights to ease the traffic or in case of an emergency to turn the traffic light green to provide an easy access to the emergency vehicles. The ITS system has to subsystems: the vehicle-to-vehicle (V2V) [14] system that can be used to transmit information to the other vehicles through the taillights and the headlights of the vehicle and vehicle-to-infrastructure (V2I) systems that can be used in order to establish a communication between the vehicles and the traffic signaling system.

Besides this introduction, the paper contains three sections as follows: in Section 2 the experimental setup is described, in Section 3 the results are presented and discussed, and Section 4 concludes the paper.

2. Materials and methods

The material that is investigated in this paper is transparent PLA. It can be found as raw material for 3D printing (filament). The sample that was used in the experiments has a diameter of 1.75 mm on the spool. The models for the parts involved in the measurements were designed in TinkerCAD. It is a 3D CAD design software that works fully online. All the models used in the experiments have a parallelepiped shape. The base for each of them is a square having the sides equal to 50 mm. The height (thickness) of the three samples used in the experiment were equal to 0.5 mm, 1 mm, and 1.5 mm. The designed samples are available at https://www.thingiverse.com/thing:3566486, so the experiment can be easily repeated.

A HE3D Tricolor 3D printer was used to print the three filament samples. The printing temperature was chosen 195°C, the temperature of the printing bed was set at 60 °C to assure a good adhesion of the first layer and avoid the distortion of the material due to cooling during printing. A nozzle with the diameter equal to 0.4 mm was used. The diameter of the nozzle was 0.4 mm. Those parameters are the usual ones for 3D printing PLA. The printing process was affected by a small systematic error, all the heights of the printed samples being 0.1 mm smaller than the designed samples. Because the samples were made using a cost effective 3D printer, this error is acceptable.

2.1. The experimental setup of the PLA reflectance spectrum measurement and of the light attenuation

The experimental setup of the PLA reflectance spectrum measurement is presented in Figure 1. It consists of a FLAME miniature spectrometer, a diffuse reflectance probe, a bifurcated fiber optic probe and the three transparent PLA materials with 0.4, 0.9, and 1.4 mm thicknesses. The spectrometer was set to measure at wavelengths between 350 nm and 1000 nm. The spectrum was measured using a diffuse reflectance probe with integrated tungsten halogen light. In order to calibrate the spectrometer, the reference spectrum was measured using a Spectralon reflectance standard and the dark spectrum was measured by using a dark block to obstruct the reflectance probe light, then the both reference spectrums were stored. The reflectance spectrum gives information about the amount of light reflected off a sample compared with a reference, which is a percentage of the reference spectrum at each wavelength. The software of the spectrometer allows saving each reflectance measurement for later processing.

In Figure 2 is presented the experimental setup for measuring how the transparent PLA samples attenuate the light passing through them depending on their thickness. The setup consists of Lutron YK-2005LX light meter, a light source (a LED mounted on a smartphone) and the three transparent PLA material samples. The samples were placed in front of the light meter’s sensor and the illuminance was measured using various lighting type selection on the light meter (Fluorescent,
Sodium Light, Mercury Light and Tungsten). For reference, the illuminance measured when nothing was placed between the light source and the light meter’s sensor was also stored, modeled as a “zero-millimeter thickness” material probe. The measurement was done in a zero-lux environment lighting conditions. A black surface was placed under the light meter sensor in order to avoid reflection.

3. Results and discussions

3.1. Results regarding the reflectance spectrum of the investigated materials

The results obtained regarding the reflectance spectrum of the transparent PLA materials for various thicknesses are illustrated in Figure 3. The graphic shows the percentage of the light reflected off the samples at each wavelength and it was observed that reflection increases as the thickness of the samples increase and that the reflection is constant over the entire spectral domain. The flatness of the reflection characteristic shows that the composition of the light passing through the studied material will be conserved, no wavelength being favorized. This is a desired parameter in many applications in which the transparent PLA could be used to produce protection housing for LEDs or light sensors. The variations at the ends of the graph, up to 400 nm and after the 900 nm, are due to the noise of the diffuse reflectance probe. The average reflectance value in the 500 nm to 800 nm domain for each material sample is presented in Table 1. The results show that the reflectance increases with 12% for each 0.5 mm, suggesting a linear increase with the thickness. The number of samples is too small to be able to draw such a strong conclusion and this subject is to be investigated in future experiments.

In order to determine transmission spectrum, a difference between the maximum percentage possible (100%) and the reflection value obtained in this experiment can be made. It can be observed that the transmission decreases as the thickness of the material increases.

| Sample thickness (mm) | Average reflectance (%) |
|-----------------------|-------------------------|
| 0.4                   | 6.96                    |
| 0.9                   | 18.82                   |
| 1.4                   | 29.49                   |
3.2. Results regarding the light attenuation of the investigated materials

The results obtained regarding the light attenuation of the transparent PLA materials for various thicknesses are illustrated in Figure 4. The illuminance was measured for all the four light meter lighting type selection and with no sample between the LED and the light meter sensor (“Thickness 0 mm”) and with the three transparent PLA samples, using the experimental setup presented in Figure 2.

For determining which lighting type is the most suitable for measuring in the given conditions, the spectrum of the LED mounted on a smartphone was determined and it is shown in Figure 5.
Figure 5. The spectrum of the LED used in the experiments that aimed at determining the light attenuation introduced by the transparent PLA.

It can be determined that the spectrum of the measured LED corresponds with the spectrum of a “warm” white LED. As determined in [15], the most suitable measurement lighting type selection for measuring “warm” white LEDs is tungsten.

4. Conclusions
The paper presented the results of an investigation regarding how transparent PLA material with various thicknesses attenuates and influences the spectral composition of the light passing through it. The design of the filament samples that were used is open source, available online, guaranteeing the easy repeatability of the experiment. The samples are parallelepipedal, with the base being a square having the sides equal to 50 mm, and each sample has a different thickness: 0.4, 0.9, and 1.4 mm.

The measurement system consists of a FLAME miniature spectrometer, a diffuse reflectance probe, a bifurcated fiber optic probe. The spectrometer was configured to measure at wavelengths between the 350 nm and 1000 nm. It was determined that the reflectance increases with approximately 12% for each 0.5 mm of thickness, suggesting a linear increase with the thickness. In order to obtain the transmission spectrum, the difference between the maximum percentage possible (100%) and the reflection value obtained in the experiment can be made. The setup used for measuring how the transparent PLA samples attenuate the light passing through them depending on their thickness consists of Lutron YK-2005LX light meter and a light source (a LED mounted on a smartphone).

From the results it can be concluded that transparent PLA has a flat attenuation spectrum between 500 nm and 800 nm, and the flatness does not seem to depend on the thickness of the material. This qualifies the material to be used in applications in which visible or infrared light passes through it, without affecting the spectral composition of that light. The thicknesses of 0.9 mm and 1.4 mm are enough to assure very good protection to a hardware system that uses LEDs or light sensors. The results about the light attenuation introduced by the material as a function of its thickness is also presented.

Future work aims to study a larger set of samples to determine the laws of variation of the reflectance and the light attenuation with the thickness of the material.
5. References

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