A NEW APPROACH IN LINE TRACKING IN SELF-DRIVING CAR USING A LOW-COST UV ORGANNIC PHOTOSENSOR

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Abstract: *Self-driving cars combine a variety of sensors to perceive their surroundings. Advanced control systems in the cars will encode sensory information to identify appropriate routes, obstacles and relevant signage. In particular, road line tracking is one of important progresses in self-driving car for future transportation. In conventional, line in the road is tracked based on the near-infrared photo-detector. The target of this paper is to present a new approach in line tracking where an UV photosensor was utilized. OLED and phototransistor firstly fabricated using organic materials. A suitable encoder circuit and PID controller then designed and implemented in to a model auto-car. The auto-car was successfully tested in University road circuit. The sensor present here is not only to demonstrate a new approach in line tracking but also to bring a lower cost sensor, leading to reduce the total costs of auto-car.*

Keywords: *low cost car sensor, photoOTFT, road line tracking, automotive.*

Received: 19/04/2020 Accepted: 1/06/2020 Published online: 14/06/2020

1. INTRODUCTION

Line tracking is widely used in a self-driving car (auto-car) for moving on the road [1-9]. Many groups have experimented with vision camera, lidar, sonar, GPS, radar as a single sensor approach to detect line, providing greater accuracy results [4]. However, those methods are relatively more expensive and not as easy to use. On the other hand, line tracking technique using inexpensive discrete sensors such as LED, and photoTFT is relatively simple and easy to implement [5-9]. As illustrated in figure 1a, a colored surface will reflect different light density, allowing the sensor to detect a different line color on a road surface. As a result, the line position is captured. Based on that, a digital PID servo algorithm programmed in a microcontroller will control the motors so that the auto-car moves forward or turns right or turns left with a certain speed.

In order to limit the influence from the visible light on the sensor, infrared wavelength region has been widely used in line tracking as shown in figure 1b. But, in practice operation, a photosensor is still attached much noise due to the sensing material naturally absorbs visible light, leading to be challenging in circuit design and car controlling. Another view, near UV or UV region can be a potential for line tracking since the ambient visible spectrum does not much overlap UV region. The reason for rare utilization of UV region for such application is that over past years, the fabrication cost of the UV photosensor is still very high. In particular, traditional UV photosensors are made from large bandgap inorganic bulk materials such as silicon and III–V semiconductors, thus the high-temperature epitaxial growth process of the heterojunction semiconductors used causes the device sensor to be complicated-to fabrication and high-cost products. Recent years, organic and nanostructured semiconductors provide a cost-effective alternative. Their large bandgap like in the inorganic counterpart can be obtained a material design, consequently excellent photodetection performance in UV range that is capable of sensing at a low cost [10-11]. However, so far, to best understanding, there have been not many studies on the application of UV sensor with organic material for line tracking in auto-car.

Aims of this work are

- To propose an new an approach based on low-cost UV photosensor with organic material
- To make an auto-car model with such photosensor that can run in a small scale road

To target that aims, UV OLED and photoOTFT were firstly fabricated. The electronic circuit design and implementation in a typical auto-car were then done. A PID control for line tracking is designed and loaded to the microcontroller. Finally, an auto-car with UV organic sensors was tested and analyzed in University road circuit.

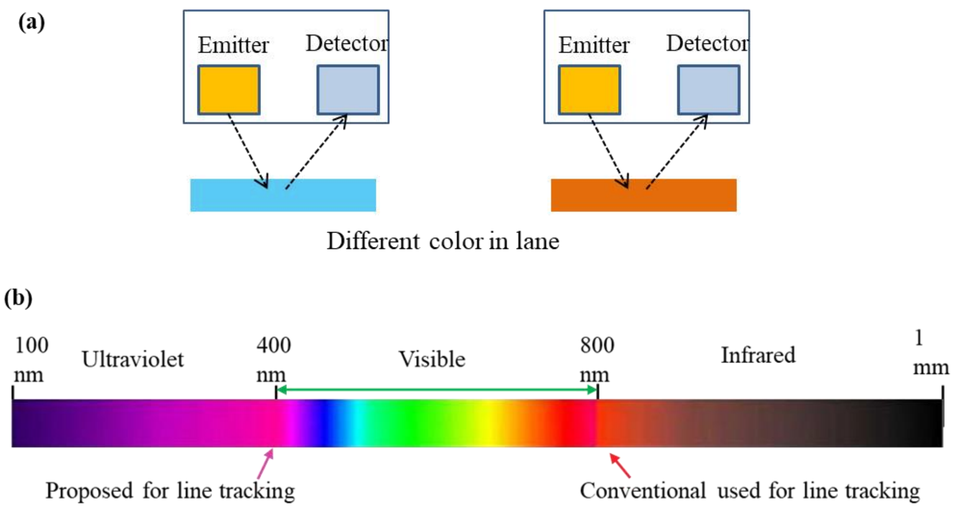

Figure 1. *a, Line tracking principle based on photosensor. b, Illustration of light spectrum and a proposed UV light for line tracking.*

2-PHOTOSENSOR FABRICATION AND CHARACTERIZATION

2.1. UV-OLED as light source

Near UV-OLED was fabricated with a device structure of glass/ITO (100 nm)/ poly(3,4-ethylenedioxythiophene) poly(styrenesulfonate) (PEDOT:PSS, 30 nm)/MoO3 (10 nm)/ 4,48-bis(9-carbazolyl)biphenyl (CBP, 80 nm)/ 2,9-dimethyl-4,7 diphenyl-1,10-phenanthroline (BCP, 60 nm)/ tris(8-hydroxyquinolato)aluminium (Alq3, 20 nm)/LiF (0.5 nm)/Al (100 nm) (see

Figure 2a). For fabrication, glass substrates coated with a 150 nm ITO layer were cleaned using ultrasonication in acetone, followed by ultrasonication in detergent, pure water, and isopropanol. Subsequently, the substrates were placed in an UV-ozone treatment chamber for 30 min. After forming a PEDOT:PSS on the ITO/glass by spincoating, all the organic layers used were thermally evaporated in a vacuum on the PEDOT:PSS/ITO layers at an evaporation rate of 0.1 nm/s. To complete the devices, a bilayer cathode consisting of a LiF layer and an Al layer was vacuum-evaporated on the Aql3 layer at an evaporation rate of 0.02 nm/s for LiF and 0.1 nm/s for Al. The device area was 4 mm^2 which was defined as the overlapped area of the ITO layer and the Al layer. This relative large area value is intentionally designed to use for auto-car.

Figure 2b shows the EL spectrum of the OLED device. It is found that the emission from the OLED's peaks at 408 nm. Figure 2c shows current density (*J*)- Voltage (*V*) – Luminance (*L*) relationship, at a voltage of 4.5 V, the *J* and *L* were found to be 136.3 mA/cm^2 and 32.3cd/m^2, respectively, that can be comparable to that of line tracking infrared LEDs [5,6].

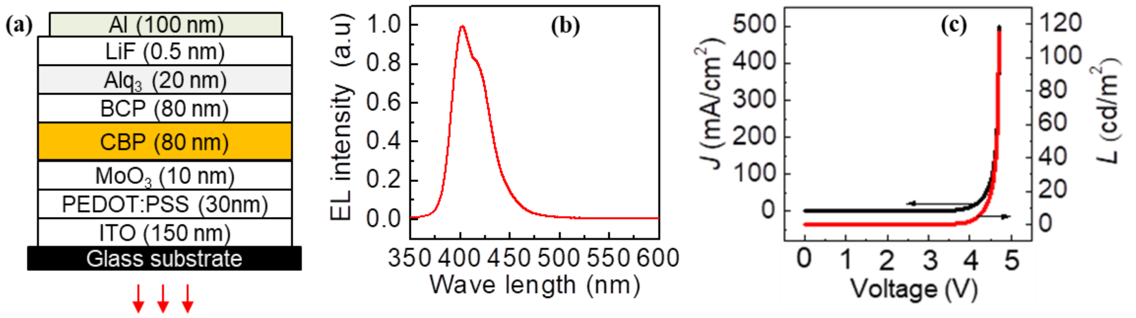

Figure 2. *a, OLED device structure. c, EL spectra. d, J-V-L relationship of OLED.*

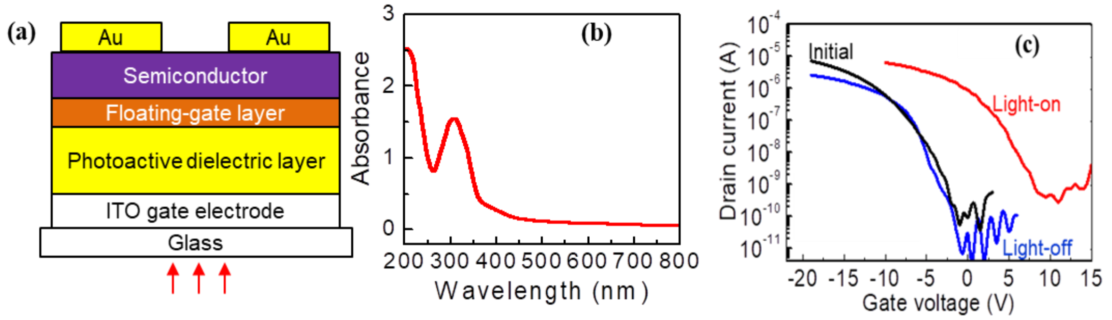

Figure 3*. a, PhotoOTFT device configuration. b, Absorbance spectra of gate dielectric layer. c, Electrical characteristics corresponding to changes in the light at voltage of 5 V.*

2.2. PhotoOTFT receiver with photoactive gate dielectric

Figure 3a shows the photoOTFT device configuration designed for line tracking. A technology method has been described in detail in recent group paper [12]. In short description, the glass substrates coated with a 100 nm gate electrode layer of ITO were cleaned using ultrasonication, followed by UV-O3 treatment. A 250 nm gate dielectric layer of DPA-CM and PMMA was prepared by spin-coating of the solution on the ITO layer at 4000 rpm for 40s, and heated on a hot plate at 100 ^{o}C for 60 min to remove residual solvent. The 10-nm-thick floating gate like layer was spin-coated onto the gate dielectric layer at 2000 rpm for 40s and dried at 100 ^oC for 2 h. A ~40 nm thick film of semiconductor was formed by conventional vacuum deposition at a deposition rate of 0.02 nm s^{-1}. Finally, the devices were completed by deposition of gold source-drain electrodes (50 nm) through a shadow mask. The channel length (*L*) and the channel width (*W*) of all transistors were 50 µm and 1000 µm, respectively.

The absorbance spectra of photoactive gate dielectric are shown in Figure 3b. Here, the DPA-CM/PMMA acts as a sensing material thanks to its strong absorption in an UV region and a stable charge-separation state which has been discussed in detail in our recent report [12]. As can be seen in figure 3b that, at 408 nm, absorbance level of the photoOTFT is relatively strong, which is suitable to use as a receiver of above OLED. Figure 3c shows the photoelectrical characteristics of the transistors in initial, after light-on by UV OLED and after light-off. In light-on case, the transfer curve shifted to a high current; after turning off, the transfer curve almost returned to the initial position, indicating that the photoOTFT responses well to the change in the OLED state.

Table 1. *Photosensor specification.*

Photosensor specification		UV OLED	PhotoOTFT
1	Power supply	5 V	5 V
2	Operating current	~ 10 mA	~ 20 µA
3	Module Size	250 mm× 250 mm (4 devices/substrate)	250 mm× 250 mm (4 devices/substrate)
4	Operating range	5 mm-200 mm	5 mm-200 mm
5	Operating angles	45°	45°
6	Output	TTL logic	TTL logic
7	Package	Thin quad flat no-lead	Thin quad flat no-lead
8	Coupling factor	5 %	5 %
9	Motor speed	1000-3000 rpm	1000-3000 rpm

The photosensor specification with respect to line tracking functionality obtained from experiments is shown in Table 1. Overall, the parameters are similar to those of commercial sensors in market. However, the cost of sensors is much lower due to cheap electronic materials and easy-fabrication processes. Table 2 presents the reflection factor with different background color. The obtained reflection factor varies from 15 % to 95 % when color changed from gray to white, helping in determination of line state of the car.

Table 2. *Reflection factor with different background color.*

Background		Reflection factor
1	Gray	15 %
2	Blue, green, yellow	45% - 75 %
3	White	95 %

3. LINE TRACKING

3.1. Circuit for photosensor

In order to convert the reflection signal to the auto-car control system, an encoder circuit is needed to create. Figure 4 shows an electronic circuit for each sensing module which includes contains OLED, potentiometers, photoOTFT, and operational amplifiers as comparator. Because of low current from photoOTFT itself and the couple factor of the reflex sensors is usually not very large, thus the photo drain currents of photoOTFT are only ~20 µA. That is hard to process the signals any further, thus the additional amplifier of LM358 is used to amplify sensor output level. Thanks to that design, the circuit can generate a digital signal with TTL at output. Furthermore, during auto-car operation, the ambient light condition and other electrical noises may be effective on the circuit; the R_1, R_2 and R_4 components were used as a potentiometer type to flexibly adjust the output level value. When a sensor on the yellow color line the circuit module reads “0” value and it on the outside of the yellow line it reads to be ‘1”. Those values are then given to the microcontroller for further processing.

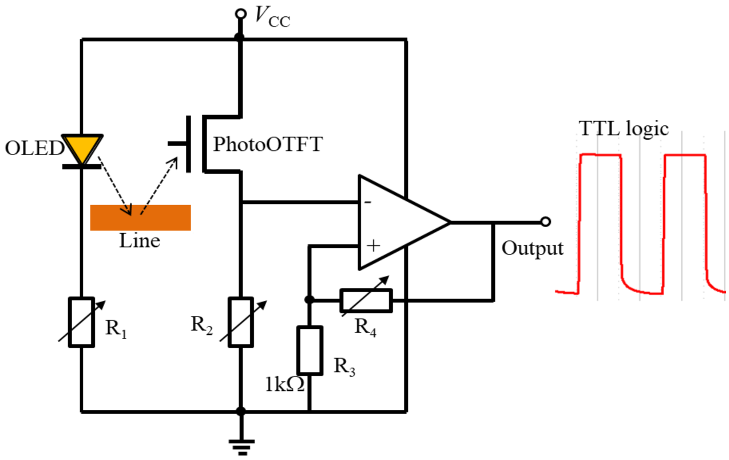

Figure 4. *Encoder circuit module for photosensor.*

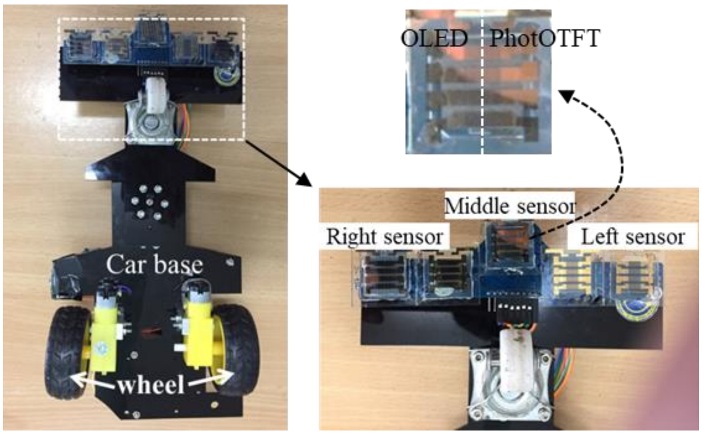

Figure 5. *Photos of autor car with photosensor mounted on car, OLED and photoOTFT on substrate module*

Figure 6. *Test track circuit made in University laboratory.*

3.2 Control flowchart and laboratory test

In order to test the UV photosensor, an available ATmega328-based auto-car as shown in figure 5 was used by replacing the sensor modules mounted at front end of the car by the photosensor circuits designed in figure 4. A test track circuit built in the University laboratory is shown in figure 6. The yellow color was chosen in line thanks to its good reflection in UV region.

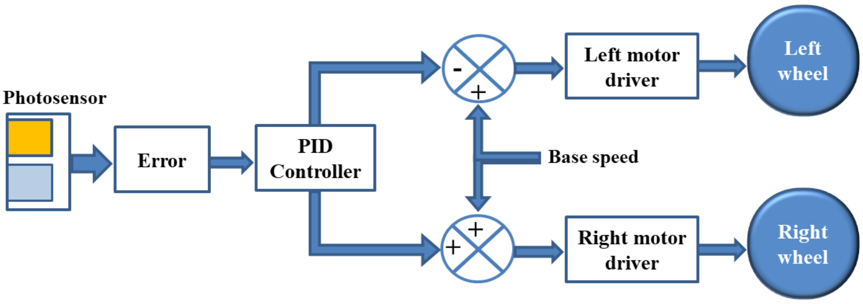

Figure 7. *Diagram control for line tracking.*

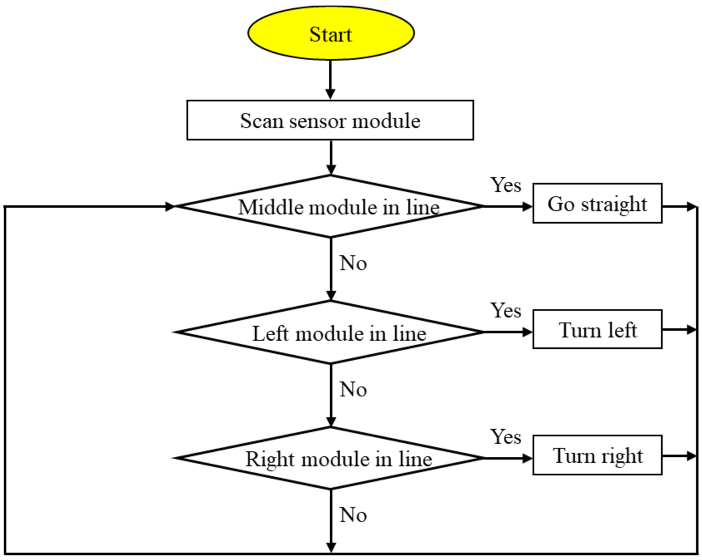

Figure 8. *Flowchart for control functionality using UV photosensor.*

The diagram control and functionality control flowchart for line tracking using UV photosensor are shown in Figure 7 and 8 which are learnt from previous work [6-8] with a modification in order to be able to apply for University test field. A simple PID control algorithm was written in C language and loaded to the microcontroller of ATmega328 to turn the motors of the car. In particular as shown in figure 9, when the middle sensor module comes in the yellow line, the right and the left motor just keep moving on the central line. On the other hand, when the right sensor comes in the yellow line region, the left motor stops while the right motor continuously moves so that the left-turn takes place and the car returns on the central yellow line. Similarly, when the left sensor comes in the yellow line then the right motor stops while the left motor continuously moves so that the right-turn takes place and the car returns on the central yellow line. As can be observed, the car is able to follow the yellow line by the trajectory made with a maximum speed of 100 cm per second, suggesting that the proposed approach is potential in practical application for auto-car.

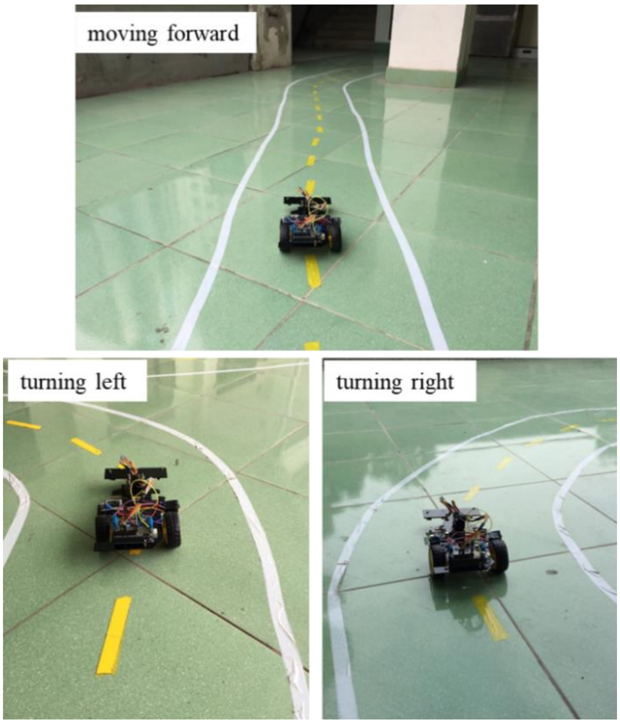

Figure 9. *Some photos from auto-car test in University laboratory.*

Table 2. *Compared performance among line tracking photosensor.*

Factor		Conventional *	In this study
1	Wavelength range	Infrared region	UV region
2	Stability in controlling	High	High
3	Implementation in car	Easy	Easy
4	Accuracy in movement	80 %	88 %
5	Fabrication technology	Complicated	Simple
6	Cost**	High	Low
*V3 module (Vietnam) [13]; TCRT5000 (Belgium) [14] **Calculated for 10.000 sensors in mass production case then compared with sensor price in Vietnam in April 2020			

Table 2 summarizes several factors of photosensor in this study in comparison with those in the conventional line tracking sensor. In terms of “stability” of system controlling and “implementation” in auto-car, both sensor types bring about similarly. However, regarding the “accuracy” in car movement on road of cars with conventional sensors of V3 module or TCRT5000 and UV sensor in this study, the number of outside during car movement was summarized, after about 50 road circuits. Accuracy of UV sensor-based auto-car (88 %) is 8 % higher than that in the car (80 %). A question is that how the UV sensor can help to obtain such positive results. This may be due to the fact that the error form UV sensor is smaller due to its low noise from the ambient light in comparison with infrared case. That makes the auto-car convenient in controlling since the motor speed is set based on trial and error for various values for the sensors as shown in figure 7. In view of “fabrication technology” UV sensor using organic materials is easier in process as presented in section 2. Also, the “cost” was estimated in a scenario that a-10.000-UV sensor will be in mass production, resulting in it is just about 60 % lower than the cost of sensor in April 2020 in Vietnam market.

4. CONCLUSION

In this experimental study, a new approach in line tracking based on an UV photosensor has been demonstrated. The OLED and photoOTFT sensors firstly were fabricated using organic materials. Operating voltage of photosensor is adaptable to the TTL logic level of 5 V. A suitable encoder circuit and PID controller then designed and implemented in to a model car. In the test, auto-car can run on the line by the trajectory in the University road circuit at high accuracy in comparison with the car using conventional photo sensor. The auto-car with sensor presents here is not only to open up a new approach in line tracking but also to bring a lower cost sensor, contributing into a reduction of the total costs of auto-car.

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