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Automation of Roadway Lighting Illuminance Measurement

Jieyi BAO[1]*, Xiaoqiang HU[2], Yi JIANG[3], Shuo LI[4]

[1] *School of Construction Management Technology, Purdue University, West Lafayette, IN 47907-2021, USA*, E-mail address: bao59@purdue.edu
[2] *School of Construction Management Technology, Purdue University, West Lafayette, IN 47907-2021, USA*, E-mail address: hu426@purdue.edu
[3] *School of Construction Management Technology, Purdue University, West Lafayette, IN 47907-2021, USA*, E-mail address: jiang2@purdue.edu
[4] *Division of Research and Development, Indiana Department of Transportation, West Lafayette, IN 47906, USA*, E-mail address: sli@indot.IN.gov

Abstract: Roadway lighting is an integral element of a highway system. Luminaires on roadways provide viewing conditions for drivers and pedestrians during nighttime in order to improve safety. It is time-consuming and labor-intensive to manually measure roadway illuminance at pre-determined spots with a handheld illuminance meter. To improve the efficiency of illuminance measurement, a remote-control electrical cart and a drone were utilized to carry an illuminance meter for the measurements. The measurements were performed on the marked grid points along the pavement. To measure the illuminance manually, one person measures illuminance at each grid point with the handheld meter and another person records the illuminance value. To measure the illuminance with the remote-control cart, the illuminance meter is attached to the cart and it measures illuminance values continuously as the cart moves along the grid lines. With the drone, the meter records the illuminance continuously as the drone carries the meter and flies along the grid line. Because the drone can fly at different heights, the measurements can be done at different altitudes. The illuminance measurements using the cart and the drone are described in detail and compared with manual measurements in this paper. It is shown through this study that automated measurements can greatly improve the efficiency of roadway illuminance data measurements.

Key words: roadway lighting, illuminance measurement, automation, remote-control cart, drone

1. INTRODUCTION

Roadway lighting is an integral part of the highway system. According to the statistics of the National Highway Traffic Safety Administration, there were 6,756,000 vehicle crashes and 33,244 of the crashes involved fatalities in 2019 [1]. About 47% of fatalities happened at nighttime, which indicates that driving at nighttime can cause more serious traffic accidents than at daytime because the traffic volume during the night is usually much less than during daytime. One of the leading causes of fatal traffic accidents during the nighttime is limited visibility. Lighting is therefore an essential element for roadway safety for motorists as well as pedestrians. Currently, the illuminance measurements are conducted manually in Indiana. Manually illuminance measuring at specified grid points is tedious and labor-intensive. To improve the efficiency of illuminance measurement, a remote control electrical cart and a drone were utilized to carry an illuminance meter for the measurements. Figure 1 shows the devices utilized in this study. The three devices are listed below:

- Illuminance meter (General Tools DLM112SD): The meter can measure illuminance automatically with adjustable time intervals from 1 second to 1 hour. See Figure 1 (a).
- Remote control electrical cart (Yahboom Professional 6WD Robot Car): The cart can be remotely controlled through a WiFi or Bluetooth connected mobile phone. See Figure 1 (b).
- Drone (the DJI Mavic 2 Zoom): The drone can carry an object up to 900 grams when flying. See Figure 1 (c).

To operate the drone at night, an anti-collision light must be used on the drone to avoid collisions. A remote pilot certification is required for one to operate the drone. It is also required to obtain a permit of operating a drone in the testing area before the operation to comply with the criteria of the Federal Aviation Administration.

(a) Illuminance meter (b) Remote control cart (c) Drone

Figure 1. Illuminance measurement devices

2. ILLUMINANCE MEASUREMENT

The illuminance measurements were conducted at the roadway lighting test facility of the Indiana Department of Transportation (INDOT). There are three lighting poles in the test facility with a size of 310 feet by 33 feet as illustrated in the photo (Figure 2). The mounting height of the poles is 25 feet and the arm length is 10 feet. The luminaire on each pole is one 250-watt high-pressure sodium (HPS) bulb. A total of 292 measurement points were marked on the pavement in 3 feet (transverse direction) by 15 feet (longitudinal direction) grids. The layout of the lighting poles with measuring grids is shown in Figure 3.

Figure 2. INDOT roadway lighting test facility

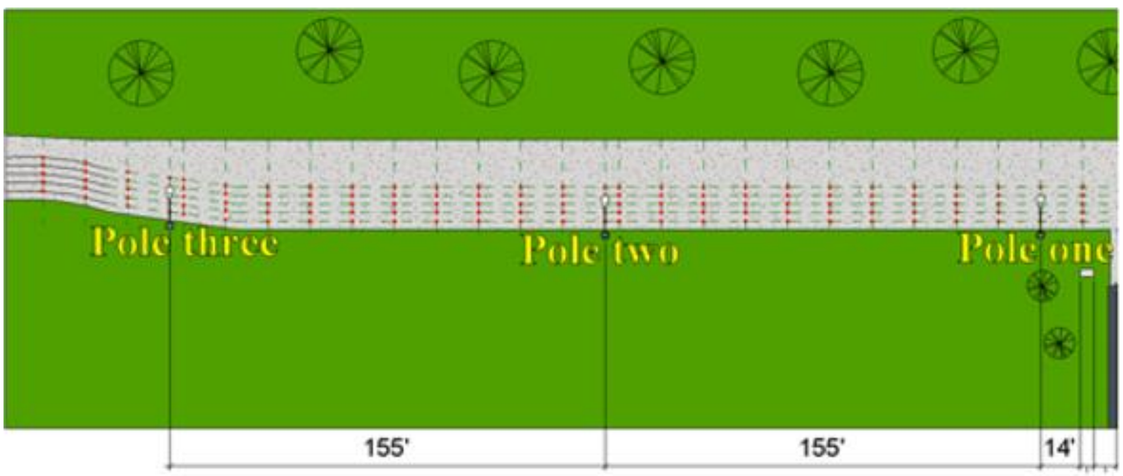

Figure 3. Layout and measuring grids of lighting poles

The measurements were performed at several nights in October 2021. The pavement was dry and clean and the weather was clear and calm. The illuminance measurement started approximately 15 minutes after sunset each night. The illuminance values were measured manually, with the cart, and with the drone as illustrated in Figure 4. Two people were involved for each of the three ways of illuminance measurements.

For the measurement with the cart, the illuminance meter was attached to the cart and the meter was set to automatically read illuminance values at one-second intervals. As the cart moved forward, the illuminance meter could read and store the illuminance values continuously.

The measurement using the drone was conducted in a similar manner to using the cart. That is, the attached illuminance meter would read and store the illuminance values at one-second intervals as the drone flew forward. The illuminance values were measured at three heights: 1.26 meters 1.74 meters, and 2.86 meters from the pavement. I was desired to fly the drone at a very low height so that the illuminance on the pavement could be measured. However, the minimum flight height was limited to 1.0 meter because when the flight height was less than 1.0 meter the drone would detect the pavement surface as an obstacle and would then activate its anti-collision function. The illuminance was measured at the three heights (1.26, 1.74, and 2.86 meters) to examine the lighting intensities at different vertical levels. The flying speed of the drone was 1.0 meter per second.

Figure 4. Manual (left), cart (middle), and drone (right) illuminance measurement

The total measurement times for the three methods are shown in Table 1 along with their respective labor intensities in terms of person-hours. The labor intensities are plotted in Figure 5 for comparison of the labor intensities of the three methods. Since the use of cart and drone was a new experience, some time was spent on adjusting the control and operations of the devices as a learning process during the measurements. As displayed in Figure 5, the labor intensity of the drone measurement decreased from 0.98 to 0.77 and then to 0.50 as the operators got more familiar with the operation process after each run of the measurement. Both Table 1 and Figure 5 clearly indicate that the two automated methods considerably improved the efficiency of illuminance measurement in comparison with the manual method. It should be pointed out that the number of persons for both cart and drone methods can be reduced to one person after gaining experience, which will further improve the efficiency of the automated measurements.

The main problems encountered for the automated measurements include the following:

1. The cart was not powerful because it moved slowly and could not move in a straight line at some locations. A more powerful cart should be used.
2. The battery of the drone could only last less than 30 minutes. Backup batteries are necessary.
3. The drone could not fly below 1.0 meter high and the illuminance on the pavement could not be directly measured.

Table 1. Labor Intensity of Measuring Methods

Measuring Method	Measuring Time (hour)	Number of Operators	Labor Intensity (person-hours)
Manual	1.330	2	2.660
Cart	0.304	2	0.608
Drone (1.26 m)	0.490	2	0.980
Drone (1.74 m)	0.383	2	0.766
Drone (2.86 m)	0.250	2	0.500
Drone Avg.	0.374	2	0.750

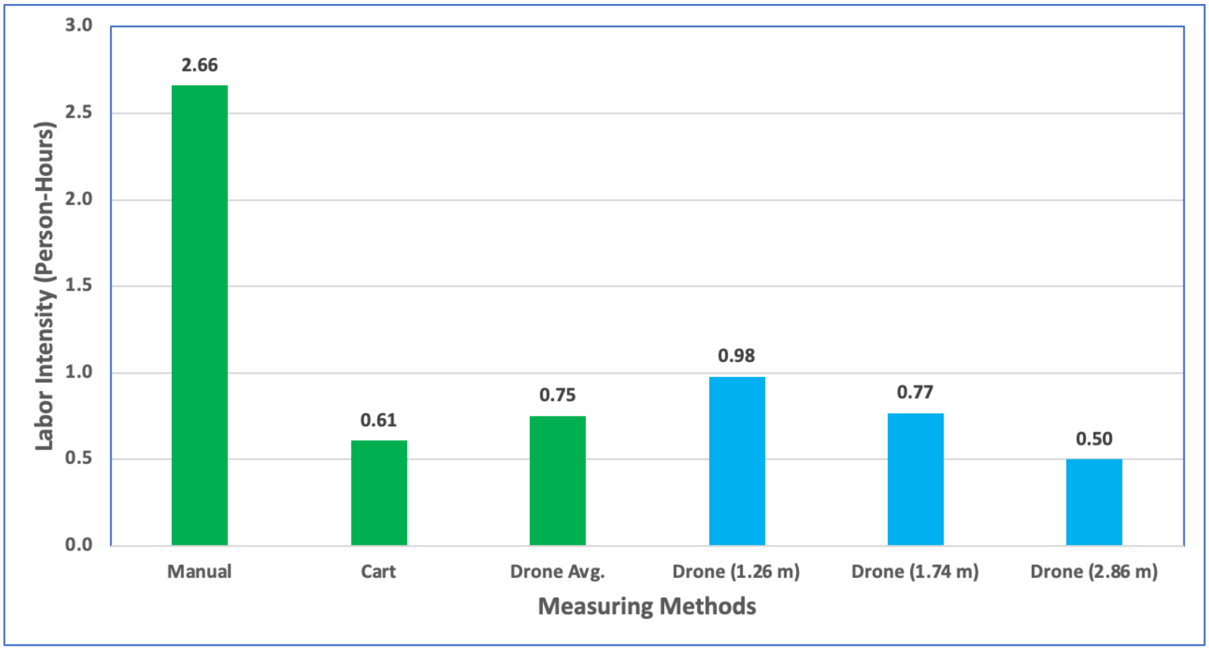

Figure 5. Comparison of labor intensities

3. MEASUREMENT RESULTS

The manually measured illuminance values over the pre-marked grid points are depicted in Figure 6 in terms of a heatmap. The horizontal axis shows the distances of the grid points from light poles and the vertical axis shows the distances of the grid points from the pavement edge. The level of illuminance is expressed in color with dark blue for high illuminance level and light blue for low illuminance level. As can be seen in the heatmap, the areas close to the light poles have high illuminance levels with dark colors and the areas in the middle between light poles have low illuminance levels with light or almost white colors.

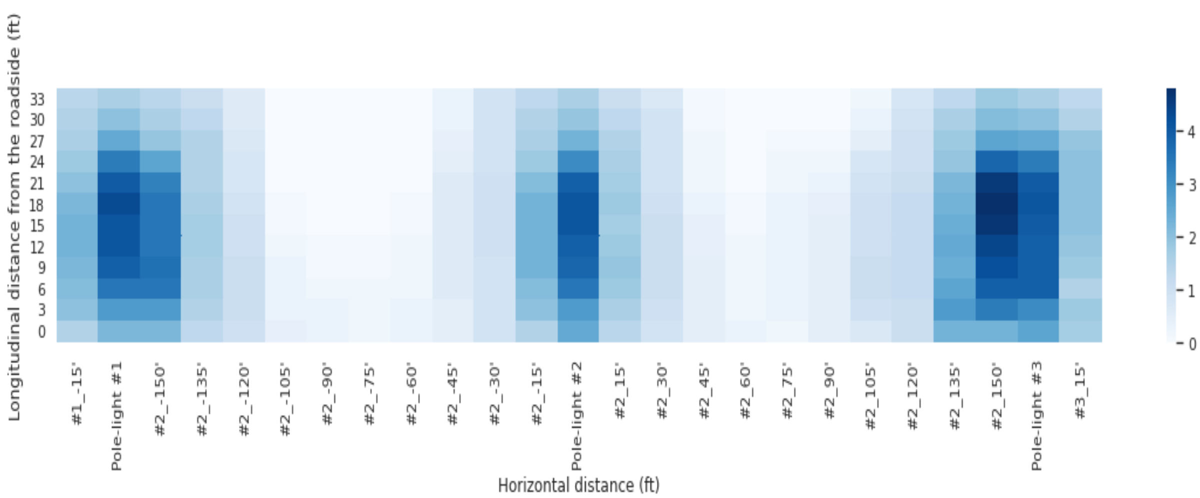

Figure 6. Heatmap of illuminance measured manually

In order to compare the illuminance values measured with different methods, the illuminance values along the line directly below the three luminaires are show in Figure 7. Since the illuminance on the pavement surface could not be measured, the drone measured illuminance values at the lowest height (1.26 m) are used in Figure 7. As expected, most of the drone measured illuminance values are lower than those from the cart and manual methods as the drone is closer to the luminaires. Although the illuminance values are generally close between cart and manual methods, the manually measured values are mostly higher. The reason for this is not known yet. It may be necessary to conduct more measurements and analyses to reveal the causes.

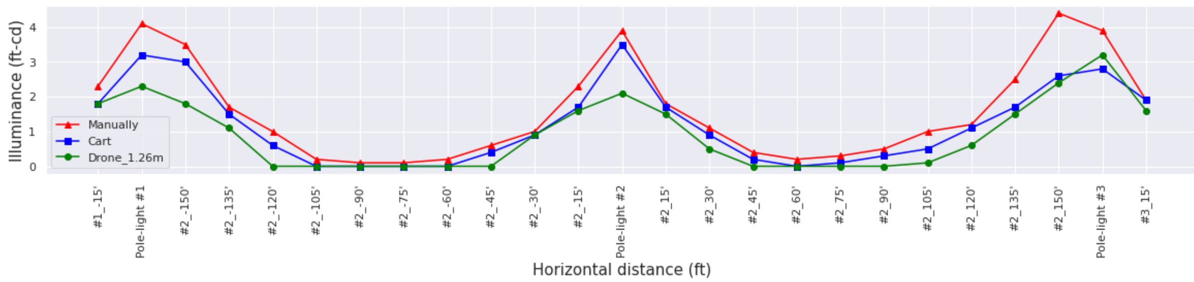

Figure 7. Illuminance values of manual and automated measurements

The use of the drone provides a unique ability to measure and analyze the illuminance levels at different heights or different distances from the luminaires. Figure 8 exhibits the illuminance values of the three heights along the line directly below the luminaires. It is interesting to see that the three curves merged when the grid points were horizontally far away from the light poles. The differences in illuminance values are the greatest under the light poles.

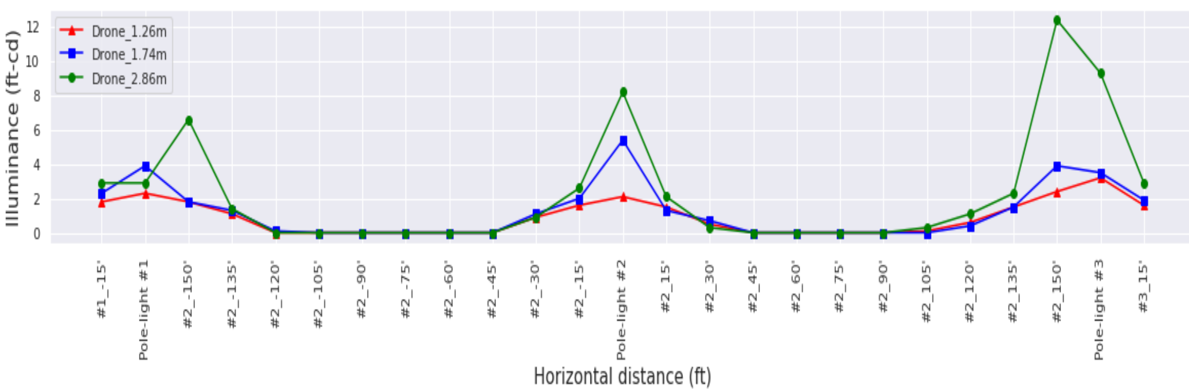

Figure 8. Illuminance measured at different heights

4. CONCLUSIONS

It is time-consuming and labor-intensive to manually measure roadway illuminance with a handheld illuminance meter. To improve the efficiency of illuminance measurement, a remote control electrical cart and a drone were utilized to carry an illuminance meter for the measurements. It is shown through this study that the automated measurements with the cart and the drone can greatly improve the efficiency of roadway illuminance measurements. The experience through this study indicates that the efficiency can be further improved with one-person operation of the cart and drone. To assure smooth measurement, it is recommended that a more powerful electrical cart be used and that backup batteries be equipped for drone operations. The vertical distribution of illuminance values can be further studied with drone-measured illuminance at different heights.

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