Smartphone-based Light Intensity Calculation Application for Accessibility Measurement

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ABSTRACT

Adequate environmental lighting is essential for healthy productive living for people with disabilities, making lighting assessment a fundamental component of environmental accessibility evaluations. Unfortunately, many evaluators do not have access to a light meter due to the bulk and cost. Therefore, we sought to create a smart phone based light meter to fill this disparity. The purpose of this paper is to describe the development of the app based light meter, Access Light, and the initial reliability testing.

As direct measurement of light using an iPhone is not possible, we developed and implemented a novel method of measuring light using proxy measures. The camera features, exposure time, ISO value and camera brightness attribute value to be significant predictors of observed lighting levels. When implemented into an app, this algorithm improved the accuracy of our app based light meter compared other apps in the iTunes store, but was less accurate than current light meters.

.INTRODUCTION

Persons with disabilities, particularly those with vision loss, are significantly affected by the lighting levels of the environments around them. Specifically, poor lighting is associated with falls, depression, poor visual performance, decreased performance in daily activities, and a lower quality of life (Bakker et al., 2004; Brunnstrom et al., 2004). Because lighting levels have such a profound impact on persons with disabilities, a lighting level assessment is essential during a environmental accessibility evaluation.

Currently, to conduct a lighting assessment, the evaluator must use a physical light meter (Young, 2012). Light meters are a bulky and expensive piece of equipment ranging from about 30 to well over 300 dollars, making it more difficult for a typical practitioner to have a light meter on hand. As part of the Access Ratings for Buildings (AR-B) project, the R&D team has worked to make environmental accessibility evaluation tools more available by duplicating common tools using a smartphone, thereby enabling more people to participate in the building evaluation process (Schwartz, 2013)

Modern smartphone come with many sensors. Using these sensors, the team has successfully measured other building features such as font size & distance (Jahangir, Majumder, Ahamed, & and Smith, 2013). Using the same principals we sought to develop a smartphone based light meter.

Unfortunately evaluating lighting can be very complex. While there are sensors that measure light intensity, apple smartphone products do not have an application programming interface for the light sensor, meaning that more creative methods that utilize other sensors to measure light are needed (Ctein, 1997).

Additionally, measuring light for accessibility purposes also poses some unique challenges. Light intensity can be measured in terms of illuminance and luminance. Luminance measures the brightness value of the reflected lights from an object. Whereas, illuminance considers all possible reflections available in a specific place and calculates the brightness value accordingly. Most light meters apps have been developed for the purposes of photography and therefore measure luminance (Komaee, A., 2010; Das et all., 2011; Jones et al., 1941). Building accessibility evaluations, however, use illuminance measured in foot candles or lux (Bakker et al., 2004). While there is some information on statistical modeling and estimation techniques as well as filtering techniques, little information is available on measuring illuminance as needed accessibility evaluations (Das et all., 2011; Jones et al., 1941). This paper examines a novel technique for measuring the light illuminance and compares it to existing apps and light meters.

TECHNICAL BACKGROUND

Because lighting levels can not be measured directly, we sought to measure light through other sensors that are activated in different lighting conditions. Hue, Saturation, lightness (HSL) is one of the most common cylindrical-coordinate representations of points in an RGB color model. Also known as hue, saturation and brightness (HSB) This model suggests the calculation of the brightness of an image form the RGB values of its pixel (Poynton, 2003; Fulton, 2010). The lightness or the brightness of a pixel is calculated in terms of the luminance value using a linear or nonlinear equation of the RGB value. Coefficients of the RGB values may vary and is usually determined by experimental results. The equations are as following.

Standard Equation
$$Luminance = (0.2126*R) + (0.7152*G) + (0.0722*B) \quad (1)$$

Linear equation from the empirical result
$$Luminance = (0.299*R + 0.587*G + 0.114*B) \quad (2)$$

Nonlinear equation from the empirical result
$$Luminance = \sqrt{0.241*R^2 + 0.691*G^2 + 0.068*B^2}$$
$$(3)$$

Using one of the above three equations, it is possible to determine the brightness value for a single pixel. To calculate the brightness value of a room or a particular

place in a building, an image can be captured and brightness value of each of the pixel can be calculated using one of the above equations. The average value the brightness of each of the pixel can be calculated to obtain the overall brightness of the image. The brightness value of the image should provide the brightness of the specific area of the building for the accessibility measurement. To obtain a more accurate result, a sequence of images can be captured and the average brightness value of these images are used instead. The algorithm is as follows.

Algorithm:
capture series of *image_count* **into** *images*.

total_brightness = 0;
for each image *im* **in** *images*
    image_brightness = 0;
    for each pixel *pi* **in** *im*
        image_brightness = image_brightness +
Luminance [using equation 1,2,3];
    end
    average_image_brightness =
image_brightness/number_of_pixels;
    total_brightness = total_brightness +
average_image_brightness;
end

brightness_value = total_brightness/image_count;
return *brightness_value;*

We found five different components that may be able to serve as a proxy measures for light illuminance. These proxy measures use the attributes of the camera (Norwood, 1940; ISO 2720:1974). Provided that,
    N = Relative aperture (F number)
    t = Exposure time
    S = ISO speed
    L = luminance
    K = light meter constant

For the reflected light, the below equation (4) represent the relationship between the luminance with the other camera properties.

$$\frac{N^2}{t} = \frac{LS}{K}. \tag{4}$$

The relationship can be interpreted as following:
- ⚔ Luminance is directly proportion to the square of relative aperture.
- ⚔ Luminance is inversely proportioned to the exposure time.
- ⚔ Luminance is inversely proportioned to the ISO speed

For illuminance the calculation is represented by the below equation:

$$\frac{N^2}{t} = \frac{ES}{C}, \tag{5}$$

where E = illuminance and C = light meter constant, The relationship with the camera properties remain same for the illuminance.

Other alternative technique is to read the camera brightness value and then establish a relationship with the light intensity in lux which can be represented using the below equation (6) (Lind, 2011).

$$light\ intensity\ in\ lux = \frac{2^{BV}}{0.0929}. \tag{6}$$

App Development

To determine how well the proxy measures of light predict actual illuminance, researchers took measurements of each camera property at different lighting levels. The measured values were processed using the techniques and the formulas described above and plotted in figures 1-5.
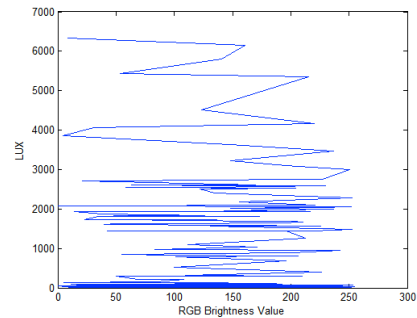

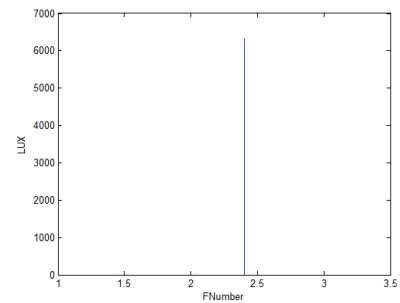Figure-1 RGB brightness with the Actual Light Intensity

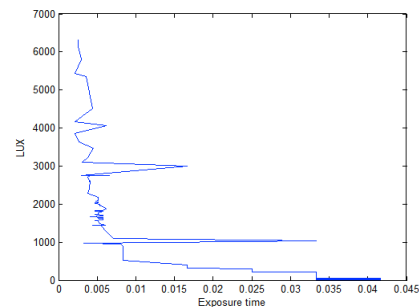Figure-2 Relative Aperture with the Actual Light Intensity

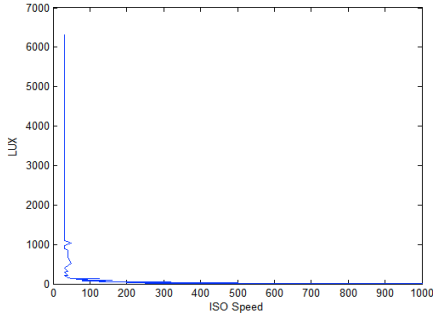Figure-3 Exposure Time with Actual Light Intensity

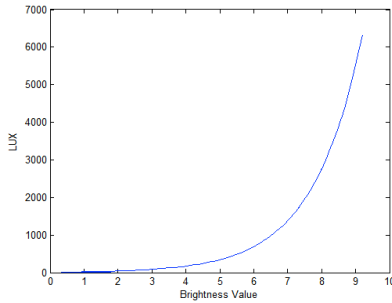Figure-4 ISO Speed with the Actual Light Intensity

Figure-5 Camera Brightness Value with the Actual Light Intensity.

Figure-1 shows a random changes in the RGB brightness value as light intensity increases. Conversely, Figure-2 demonstrates that the aperture value remains constant as light intensity increases. The changes in RGB brightness and aperture value indicate that these measures are not to be useful in calculating light intensity. The other three measures, exposure time, ISO value and the camera brightness attribute value all increased as light intensity increased, demonstrating that these values may be helpful in determining true illuminance.

The visual findings were then confirmed by statistical test. We performed a least square regression followed by a statistical t-test to find out the statistical significance of the associated variables. Camera brightness, exposure time, and ISO speed were found to be significant predictors of observed lighting levels.

PROPOSED NOVEL APPROACH

Based on the findings above, the formula for lighting intensity was modified to be as follows:

$$Light\ intensity = \frac{K * 2^{BV}}{\frac{S}{t} * 0.0929} \qquad (7)$$

From further regression analysis, the value of K is typically found around 750. An algorithm is proposed based on the above equation (7) which is presented below.

Algorithm:
capture series of *image_count* **into** *images*.

total_brightness = 0;
for each image *im* **in** *images*
   *image_brightness = 750*power(BV,2)/(0.0929*S/t);*

   total brightness = total_brightness + image_brightness;
end

brightness_value = total_brightness/image_count;
return *brightness_value;*

Using the above algorithm, we developed a smart phone application to measure light called Access Light. Access Light is capable of capturing a series of images and perform necessary processing, a screen shot of the alpha version of the app can be seen in Figure 6.
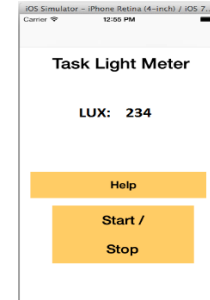

Figure-6 Application User Interface.

METHODS

Once the application was developed, preliminary testing commenced. We compared Access Light to a light meter and a similar application from the app store. "LightMeter by Whitegoods" was chosen because it is one of the few app available in the iTunes store that measure illuminance and gives readings in lux and foot candles. Researchers also tested Access Light with and without a Luxi,, or a device that attaches to the iPhone to even out light dispersion, allowing for the measurement the light falling on the subject rather than the light reflected by the surrounding. Researchers took five light level readings across ten different lighting situations. The best of the five readings were used. Mean Absolute Percent Error (MAPE) was used to compare overall accuracy. MAPE is the absolute value of the difference between the observed and the actual light intensity over the actual light intensity.

RESULTS

Access Light demonstrates improved accuracy compared to the existing iPhone application for the light meter as seen in Table 1. Use of the Luxi did not show an overall improvement in terms of MAPE. Even though for daylight and fluorescent light Access Light with a Luxi provided the best result, the Luxi did not improve overall accuracy. While the MAPE for Access Light was only 15.8, the tool was off by 0 to 428 lux. As the lighting intensity increased, the accuracy of the tool decreased.

Environment	Light Meter (Used as Ref.)	Existing Application	Our Application	
			No Luxi	With Luxi
Dark	3	2	3	1
Bulb far	36	22	28	20
Bulb obstacle	18	9	11	7
Bulb near	189	110	157	163
Fluorescent far	246	220	283	261
Fluorescent obstacle	121	74	152	118
Fluorescent near	785	659	903	832
Daylight far	3418	4334	3187	3267
Daylight obstacle	2210	2845	1984	2102
Daylight near	6340	11093	5912	6092
Error (MAPE)		**36%**	**15.8%**	**21.4%**

Table-1: Test Result Comparison

DISCUSSION & CONCLUSION

This paper documents exciting new methods OF measuring illuminance using an iPhone. Exposure time, ISO value and the camera brightness attribute value are all significant predictors of environmental lighting levels. Therefore we developed Access Light to measure light using these proxy measures. While Access Light (using this new algorithm) demonstrates improvements in accuracy compared to other apps in the app store, the tool still lacks the level of accuracy needed for accessibility evaluation. Future research is needed to create more accurate measures of illuminance.

ACKNOWLEDGEMENTS

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