Feasibility of a smart-phone ambient light sensor as a tachometer

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This paper explores the use of the ambient light sensor on an LG G3 smartphone as a tachometer. The accuracy and response time of the sensor are determined with the aim of providing smart-phone users insight on scope of its applications. A method of determining the speed (in RPM) of a rotating chopper from variations in light intensity is presented and the results are compared to and existing laser tachometer. On the condition that the time the chopper takes to pass the sensor is greater than the response time of the sensor, the percent difference between the laser tachometer and the smart-phone is less than 1% under ideal lighting conditions for distances between the sensor and the chopper of up to 5cm. In less ideal lighting conditions, the percent difference approaches 5% as the distance between the sensor and the chopper approaches 5cm. The response time of the ambient light sensor was found to be between 0.03 and 0.04s ± 2%.

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I. INTRODUCTION

Due to advances in photoconductor technology, ambient light sensors are becoming increasingly popular in smart-phones and other consumer electronics.[1] The most common application of the ambient light sensors is auto-brightness control on LCD screens which uses the intensity of light that is measured to adjust screen brightness to an ideal level for the user.[2] In addition to this in-phone application, it has been demonstrated that the information from ambient light sensors on smart-phones can be easily extracted for use in other applications outside of the phone functionality. Educators are recognizing the value of smart-phone ambient light sensors as tools to engage students.[34] In his paper, Fu describes a design of a device that uses the smart-phone ambient light sensor to determine the concentration of biomarker analytes in a nanosubstrate.[5]

One application of the ambient light sensors on smart-phones that seems undeveloped, is a tachometer or RPM counter. If RPM information can be determined using a smart-phone ambient light sensor, more applications such as odometers and speedometers become feasible as well. Unfortunately, very little information is available to smart-phone users about the characteristics of the on-board ambient light sensor. For measuring rotational speed, the most critical characteristic of the sensor is the response time of the photodetector as it will determine the maximum RPM count that can be accurately measured.

In this paper the feasibility of using the ambient light sensor on an LG G3 smart-phone as tachometer is examined. A method for determining rotational speed from the light intensity data is presented and the accuracy of the ambient light sensor method is compared to an existing laser photo tachometer. The data collected is used to form an estimated range of the response time of the ambient light sensor so that the possible scope of its application can be more easily determined.

II. EXPERIMENTAL

A chopper attached to an Adafruit 2941 DC motor was used to block light in front of the ambient light sensor on an LG G3 smart-phone. The motor was controlled using a Raspberry Pi with a LS293D motor driver and powered by a 9V battery. By use of pulse width modulation, the speed of the chopper was varied. The intensity of light entering the ambient light sensor was measured and recorded using the Physics Toolbox Light Sensor app available on Android smart-phones.

First, a 6cm wide chopper was positioned 0.5 centimeters away from the smart-phone sensor in a dark room. A 13W, soft white (2700K) fluorescent lamp was placed 60 cm infront of the phone and directed at the sensor, light intensity data was collected at varied chopper speeds. Further testing with the 6cm chopper blade was performed by changing the lighting conditions in the room to a bright room (room light intensity = 75lux as measured by the ambient light sensor) with the lamp 60 cm away from the sensor, followed by a bright room without the lamp. The distance between the chopper and the sensor was also varied to 1cm and 5cm. The width of the chopper was then reduced to 2.5cm to investigate the response time of the sensor. The 2.5cm wide chopper was again placed 0.5cm from the sensor in a dark room with a single light source directed toward the sensor.

All of the results from the smart-phone ambient light sensor were compared to a Cybertech DT2234A Laser Photo Tachometer.

III. BASIC THEORY

The relationship between the speed of the chopper in RPM and the light intensity data measured by the ambient light sensor on the LG G3 cell phone can be determined by counting the light intensity peaks in a specified time interval. The relationship is shown in Equation 1 where n_{peaks} is the number of light intensity peaks, t_f is the time at which the final peak occurred and t_i is the time at which the first light intensity peak occurred in seconds.

$$Chopper\ Speed\ in\ RPM = \frac{n_{peaks} - 1}{t_f - t_i} \times 60s \qquad (1)$$

The numerator is $n_{peaks} - 1$ because the first light intensity peak is the initial value measured before the chopper has made one revolution which must be subtracted from the total number of peaks.

The chopper speed in RPM can be related to the angular velocity of the chopper, ω and the linear velocity, v, by the Equations 2 and 3 where r is the radius of the chopper at the point which it passes the ambient light sensor.

$$\omega = \frac{Chopper\ Speed\ in\ RPM}{60seconds} \times 2\pi \frac{rads}{rev} \quad (\frac{rads}{s}) \quad (2)$$

$$v = \omega \times r \quad (\frac{cm}{s}) \qquad (3)$$

From the linear velocity and the width of chopper blade, the length of time that light is blocked from entering the sensor is found using the relation in Equation 4.

$$t_c = \frac{width_{chopper}}{v} \qquad (4)$$

Ambient light sensors are made from either photodiodes or phototransistors that have high responsivity under ambient light.[2] A characteristic of all of these light detecting technologies is the response time (or rise time) of the sensor which is the time it takes the sensor to change from 10% to 90% of its maximum value.[6] Abrupt changes in light intesity which occur quicker than the response time will be unnoticed by the sensor and cannot be measured.

IV. RESULTS AND DISCUSSION

Table I shows the speed of the 6cm chopper determined using the LG G3 ambient light sensor method compared to the laser tachometer. The value tabulated is the mean value of three trials performed using the ambient light sensor and is accompanied by the standard deviation. The percent difference between the chopper speed determined using the LG G3 and the chopper speed measured with the laser tachometer is less than one percent for all cases indicating that the results agree well. The results are plotted in Figure 1 where we can easily see that the rotational speeds found using the LG G3 agree with the laser tachometer within the standard deviation (shown as error bars on the graph in Figure 1) at all chopper speeds. The uncertainty in the CyberTech laser tachometer is 0.05% (as quoted by the manufacturer) so error bars for those measurements are not resolvable on a graph of this scale.

The light intensity data measured using the 6cm chopper blade can be seen in Figure 2a and 2b with the motor at 20% and 80% duty cycle. Because of the rotating chopper which blocks the ambient light sensor, it is expected that a near zero light intensity will be measured once per rotation. However, at the faster motor speed, in Figure 2b, some of the light intensity minima are not near zero. Fortunately, this does not affect the RPM results extracted from the data unless there is no light intensity decrease detected in a rotation. If no light intensity change is detected, then the number of light intensity peaks will be less than expected. Figure 3 shows that this effect becomes worse when in a bright room. The minimum values of light intensity measured in a bright room at 80% duty cycle are much less consistent near zero which could lead errors in the number of peaks measured.

Less direct lighting conditions and a larger distance between the sensor and the chopper blade further test the robustness of the ambient light sensor tachometer system. The results for these conditions are shown in Table II and are plotted in Figure 4. It is obvious from the graphs shown in Figure 4 that only the direct lamp light condition (a dark room with light from one lamp directed at the sensor) agrees with the speed measured by the tachometer within the standard deviation of the ambient light sensor measurements (shown as error bars on the plot in Figure 4). However, the percent difference between the LG G3 determined RPM values and the laser

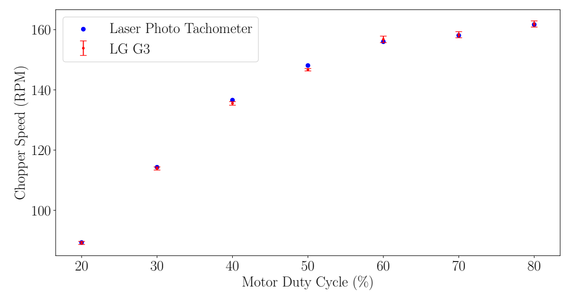


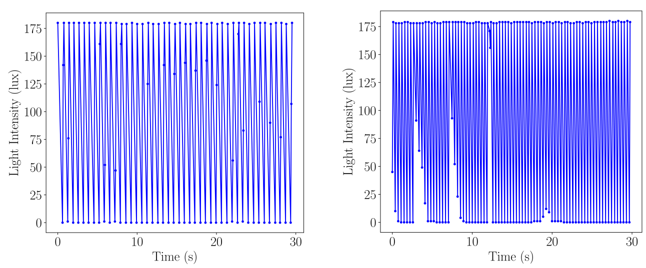
FIG. 1: Chopper speed measured by LG G3 ambient light sensor method and by the laser tachometer for the 6cm chopper width positioned 0.5cm from the sensor in dark room with lamp light

TABLE I: Chopper speed measured with smart-phone ambient light sensor and optical laser tachometer for 6cm chopper width positioned 0.5cm from the sensor in dark room with lamp light

Motor	*Chopper Speed (RPM)*			
Duty Cycle(%)	LG G3	σ	Cybertech	% Difference
20	89.17	0.51	89.3	0.15
30	113.89	0.53	114.3	0.36
40	135.51	0.60	136.6	0.80
50	146.70	0.40	148.1	0.94
60	156.77	1.07	156.0	0.50
70	158.32	1.00	158.1	0.14
80	161.89	1.02	161.7	0.12

TABLE II: RPM measured under different lighting and distances between the chopper & sensor (Duty Cycle=80%)

Lighting Condition	Chopper Distance (cm)	Measured Chopper Speed (RPM)	σ (RPM)	% Difference
Lamp Light	0.5	161.89	1.02	0.12
	1	161.95	1.12	0.15
	5	162.17	1.67	0.29
	CyberTech Laser Tachometer	161.7	-	-
Bright Room with Lamp	0.5	158.38	2.67	1.75
	1	157.20	1.98	2.48
	5	154.52	3.73	4.14
	CyberTech Laser Tachometer	161.20	-	-
Bright Room	0.5	159.54	1.66	1.52
	1	157.99	2.12	2.47
	5	155.34	3.60	4.11
	CyberTech Laser Tachometer	162.0	-	-



(a) Duty Cycle=20%

(b) Duty Cycle=80%

FIG. 2: Light intensity data collected using the 6cm chopper blade 0.5cm away from the sensor with dark room and lamp light

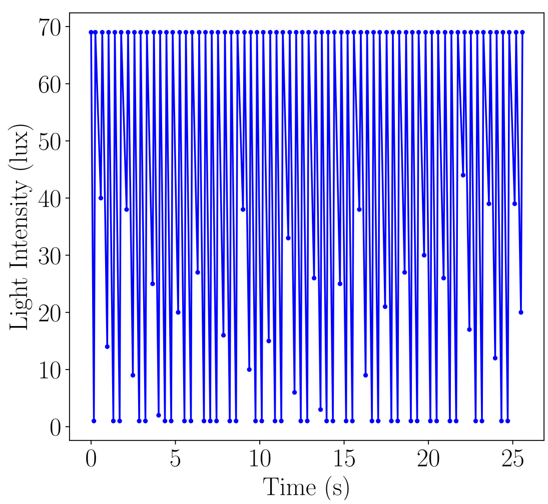


FIG. 3: Light intensity data collected using the 6cm chopper blade 0.5cm away from the sensor in a bright room with motor duty cycle = 80%

tachometer measured values is below 5 percent for all the measurements made regardless of the lighting conditions or distance between the chopper and the sensor.

When the experiment was run with the more diffused lighting conditions, the presence of a direct light source (the lamp) did not influence the results. The two sets of results which were obtained in a bright room (with and without the lamp) have very similar percent difference when compared to the laser tachometer. The percent difference for both of these lighting conditions increases to just under five percent as the distance between the chopper blade and the sensor increases to 5cm. This trend is not observed when only the direct lamp light is present; the error remains under one percent for all of the chopper blade distances.

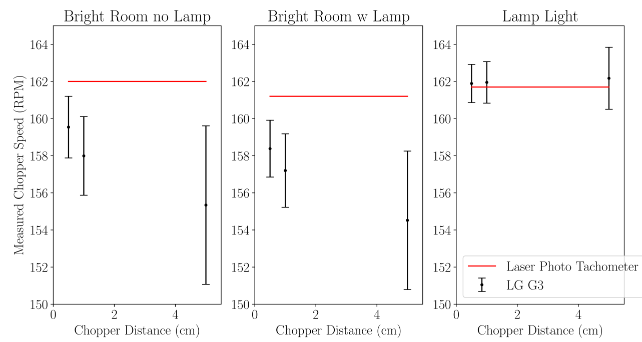


FIG. 4: Chopper speed vs. distance between the chopper blade and the sensor in a bright room, bright room with lamp light directed at the sensor and a dark room with lamp light (duty cycle = 80%)

When the blade width of the chopper was reduced to 2.5cm the range of speeds that could be determined using the LG G3 smart-phone became very limited. In Table III it becomes obvious that the ambient light sensor could not accurately record the changes in light intensity with speeds higher than 80RPM. The percent difference when compared to the laser tachometer was greater than fifty percent at this speed. From this we can see that the length of time that the chopper blade is blocking light into the sensor has been reduced to below the response time of the ambient light sensor system within the smart-phone. This becomes even more obvious from the lack of periodicity in the light intensity measured by the LG G3 shown in Figure 5.

Since 82.09 RPM was the highest chopper speed mea-

TABLE III: Chopper speed measured with smartphone ambient light sensor and laser tachometer for 2.5cm chopper width positioned 0.5cm from the ambient light sensor in a dark room with lamp light

Motor Duty Cycle (%)	*Chopper Speed (RPM)* LG G3	CyberTech	% Difference
20	82.09	83.21	1.33
30	43.70	112.34	61.08
40	53.77	130.12	58.64
50	69.22	146.20	52.65

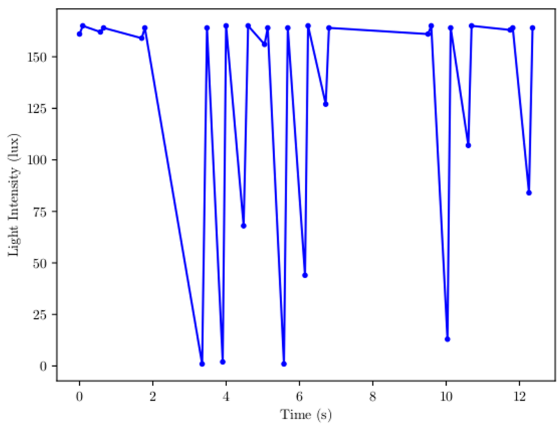


FIG. 5: Light intensity data collected with 2.5cm chopper blade running at 112RPM (Motor Duty Cycle=30%)

sured using the ambient light sensor that agreed with the reading from the laser tachometer, this speed can be used to determine the upper limit of the response time of the ambient light sensor using Equations 3 and 4.

$$v = \frac{83.21rev}{60s} \times 2\pi\ \frac{rad}{rev}\ \times 7\text{cm} = 60.18\ \text{cm}\frac{}{s}$$

$$t_{c\ 83RPM} = \frac{2.5cm}{60.18\frac{cm}{s}} = 0.04s$$

It is obvious from Table III that the time in which the chopper blade was blocking the light into the sensor was reduced below the response time of the sensor somewhere between the 20 percent and 30 percent duty cycle (83 and 112 RPM) of the motor. The amount of time the sensor was blocked for when the motor was running at 30 percent duty cycle can be used as the lower limit of the response time of the ambient light sensor in the LG G3 smart-phone.

$$v = \frac{112.34rev}{60s} \times 2\pi\frac{rad}{rev} \times 7cm = 82.34\frac{cm}{s}$$

$$t_{c\ 112RPM} = \frac{2.5cm}{82.34\frac{cm}{s}} = 0.03s$$

The uncertainty in the laser tachometer of 0.05% and uncertainty in the chopper radius and width of 0.05cm was added in quadrature (as relative uncertainty) to find the uncertainty in the upper and lower limit of the response time. Thus we can state that the response time of the ambient light sensor falls within the range

$$0.03s < t_{response} \leq 0.04s \pm 2\%$$

V. CONCLUSION

This paper demonstrated the use of the ambient light sensor on an LG G3 smart-phone as a tachometer by recording the variation in light intensity when the sensor was blocked by a rotating chopper. When the time that the chopper took to pass the sensor was greater than the response time of the sensor, the ambient light sensor was used determine the RPM of the chopper within 1% error in a dark room with a lamp directed at the sensor. In a brightly lit room, the error in the ambient light sensor technique was between 1-5% (when compared to the CyberTek Laser Photo Tachometer) depending on the distance between the sensor and the chopper blade. The response time of the ambient light sensor was found to be between 0.03 and 0.04s ± 2%.

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