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Optoelectronic Assessment of the Estimote Location Beacon

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ABSTRACT

The Estimote Location Beacon™ is the latest addition to the Hybrid.Beacon DST Group project. This project uses inexpensive commercial components to assess the potential for increased situational awareness in tactical scenarios. The ability of the Estimote Location Beacon to generate, and participate in a Bluetooth-based Mesh Network, along with an amazing array of on-board sensors, makes it an area of high potential for innovation. This Technical Note will focus on one of the Beacon's sensors, its ambient light capability. The next Technical Note in this series will focus on the magnetometer.

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Executive Summary

This Technical Note establishes a first-pass assessment of the effectiveness of the ambient light sensing capability of the Estimote Location Beacon. Estimote is the market leader in development of highly sensitive Internet of Things Bluetooth components. As part of an innovation initiative for modernising the Australian Defence Force, a project was formed to demonstrate a practical application of this technology. By combining an existing DST algorithm, called Hybrid Registration, with these new beacons, the Hybrid.Beacon project was started. The Hybrid.Beacon project has been running in the Australian Defence Science and Technology Group since October 2015. There are two main technological initiatives in this project. The first is an iPhone-based app that has been written to demonstrate the potential for integrating image and video information with the iPhone's on-board sensors. The second involves exploiting these beacons to assist the soldier, or search and rescue technician, by providing enhanced situational awareness.

As this device is being integrated into the Hybrid.Beacon project, certain tactical information may be derived from knowing ambient light. For example, if the beacon is positioned in an office, it will signal a change in ambient light when the occupant enters and turns on the office light.

This is the first of a series of five Technical Notes assessing each of the capabilities of the beacon, the others being barometer, magnetometer, accelerometer, and temperature. Of course, the primary reason for the beacons is to potentially assist in enhancing spatial awareness in time-critical scenarios, especially when GPS-denied. This is accomplished through the Bluetooth-based mesh networking capability.

When compared to a standard light meter the Estimote Location Beacon performs well. With only a minor adjustment it is able to relay accurate illuminance (Lux) information. However, it does not respond quickly to changes in light levels, which is essential to understand prior to tactical use. This Technical Note may be republished as a Technical Report (which typically contains a higher level of technical detail and experimental rigor) once additional microprocessor level information is known about the beacon.

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1. Introduction

This Technical Note assesses the effectiveness of the Estimote Location Beacon's ability to measure light. This new Internet of Things beacon device features five remote sensing capabilities in addition to its primary tasks of mesh networking and Bluetooth communications. Among these five sensors is a photosensitive semiconductor device mounted on the small motherboard of the Estimote Location Beacon (see Table 1). A small comparison study between a commercial Light Meter (see Appendix for specifications and usage) and an Estimote Location Beacon was carried out. The results, measures of Illuminance in units of Lux, are plotted and discussed below. A brief test of sensor responsiveness was also completed. To conclude, a detailed study of the effect of the translucent silicon material on the performance of the Estimote Location Beacon's photosensitive diode is completed.

Table 1 Specifications for the Estimote Location Beacon (Krzych & Kostka, 2016).

Battery life	5 years
Range	200 metres
Thickness	24 millimetres
iBeacon™ or Eddystone™ packets	8 simultaneously
Additional packets	connectivity, telemetry
Built-in sensors	motion, temperature, ambient light, magnetometer,
Additional tech	mesh networking, GPIO, RTC, LED, 1 Mb EEPROM, programmable NFC

2. Methods

2.1 Background

Both the Light Meter and the Estimote Location Beacon measure Illuminance, given in units of Lux, equivalent to lumens over an area (lm m^{-2}). Illuminance (E_v) is the density of the luminous flux incident on a given point of a surface or a plane. It is defined as $E_v = \frac{d\Phi_v}{dA}$ where $d\Phi_v$ is the luminous flux incident on an element dA of the surface containing the point (National Institute of Standards and Technology, 1997). The relationship of Illuminance with the other photometric and radiometric quantities is shown in Table 2.

Table 2 Quantities and unit used in photometry and radiometry (NIST.gov)

Photometric quantity	Unit	relationship with lumen	Radiometric Quantity	Unit
Luminous flux	lm (lumen)		Radiant flux	W (watt)
Luminous intensity	cd (candela)	lm sr^{-1}	Radiant intensity	W sr^{-1}
Illuminance	lx (lux)	lm m^{-2}	Irradiance	W m^{-2}
Luminance	cd m^{-2}	lm sr^{-1} m^{-2}	Radiance	W sr^{-1} m^{-2}
Luminous exitance	lm m^{-2}		Radiant exitance	W m^{-2}
Luminous exposure	lx s		Radiant exposure	W m^{-2} s
Luminous energy	lm s		Radiant energy	J (joule)
Color temperature	K (kelvin)		Radiance temperature	K

As this publication is a Technical Note, for sake of brevity we limit ourselves to study of Lux. The numerous downstream characteristics of photosensitive diodes, in relation to the performance of the Estimote Location Beacon, will be the focus of a more detailed Technical Report which will include assessment of all five sensors.

2.2 Gathering data from Light Meter and Estimote Location Beacon

A small Light Meter (40 mm diameter, see Appendix for additional technical specifications) was placed next to an Estimote Location Beacon at thirteen different locations at various times of day (see Figure 1). These times ranged from sunrise to sunset. A number of indoor locations were included as well. The Light Meter, a standard consumer quality device, was positioned precisely so that the measurement dome central angle was in line with the light source (see Figure 2). This was also done with the Estimote Location Beacon. This was a particularly important variable to control as minor angular deviations caused significant numerical variation in Lux. To learn more about the photosensitive diodes within both sensors the units were disassembled[1] and a laboratory camera used to examine them (see Figures 3–6). Based on the measurement grid used during photography the area of the Light Meter's photosensitive diode is 15 mm x 17 mm = 255 mm^2. However, upon closer inspection the active area inside the casing was 3.5 mm x 5 mm = 17.5 mm^2. The photosensitive diode within the Estimote Location Beacon is adjacent to a small, yet very intense, yellow LED on the motherboard. This LED flashes through the small circular silicon depression on the top of the beacon. This flashing indicates the unit is actively being controlled. Based on the measurement grid used during photography the area of the semiconductor is 3 mm x 3 mm = 9 mm^2. The pink silicon cover of the Estimote Location Beacon was removed and inverted for detailed observation

[1] No detailed electronics assessment was done for either the Light Meter or the Estimote Location Beacon. The purpose for disassembly was to understand the influences on the photosensitive diodes.

of the translucent circular area meant to allow light into the interior of the unit (see Figure 7).

Figure 1 The experimental setup as used to collect 13 pairs of data points. (A) The Light Meter control unit, showing 9890 Lux; (B) the Light Meter light collecting dome, covering a light sensitive semiconductor device; (C) the Estimote Location Beacon, note the small (3 mm diameter) circular depression in the silicon housing covering the photosensitive diode embedded inside.

Figure 2 A close up view of the Light Meter collecting dome, measuring 40 mm diameter across the diffuser.

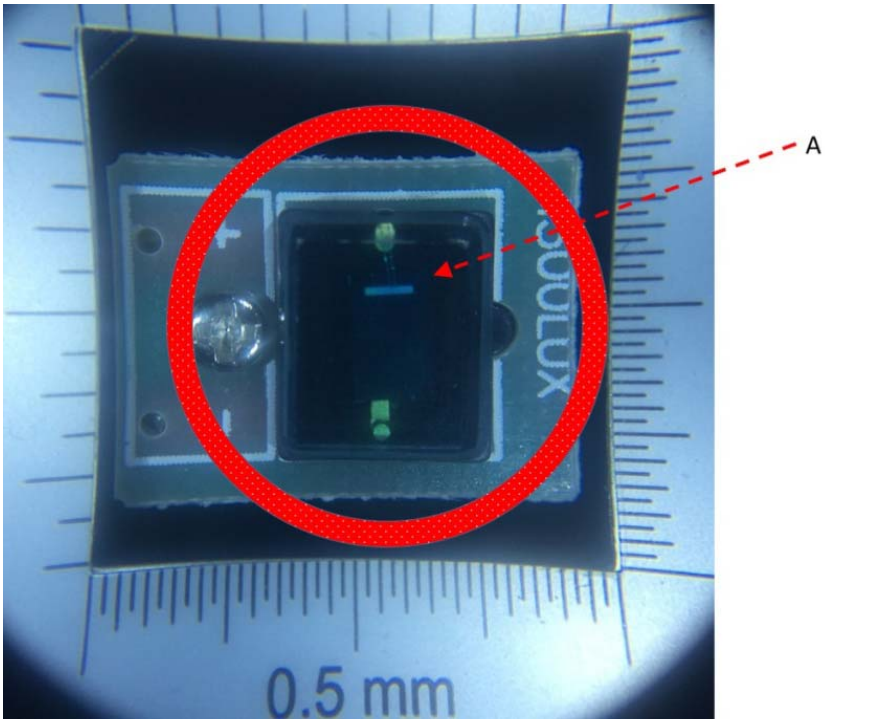

Figure 3 *A close up view of the photosensitive semiconductor device (A) underneath the smooth white Light Meter diffuser. Note that the device is completely contained within the red circle. A single Philips screw holds it in position. Polarity markings for the sensor are observed as well.*

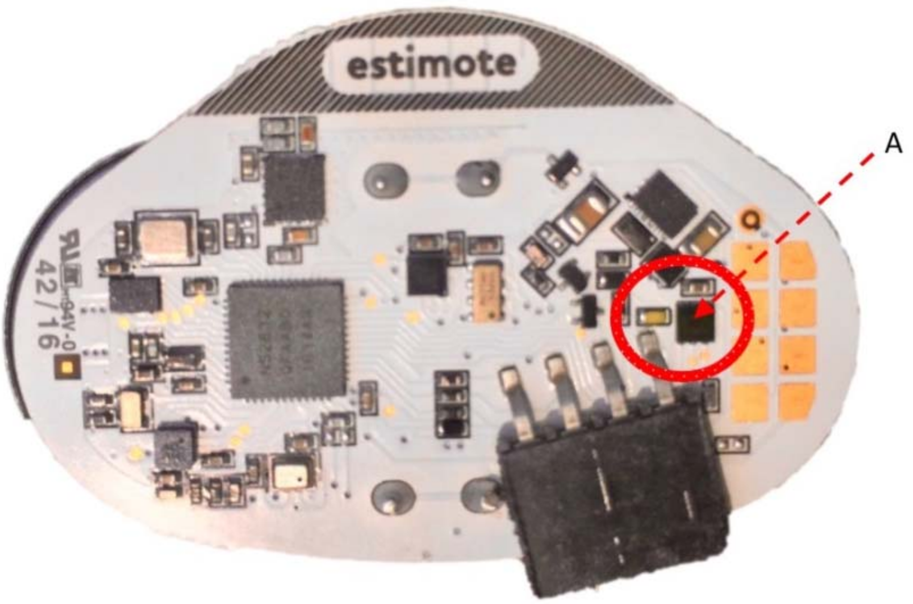

Figure 4 *The small motherboard of the Estimote Location Beacon showing (in red) the square black photosensitive diode (A) to the right of a small, but very intense yellow LED. Note the use of the red circle to introduce a scale for comparison to further figures.*

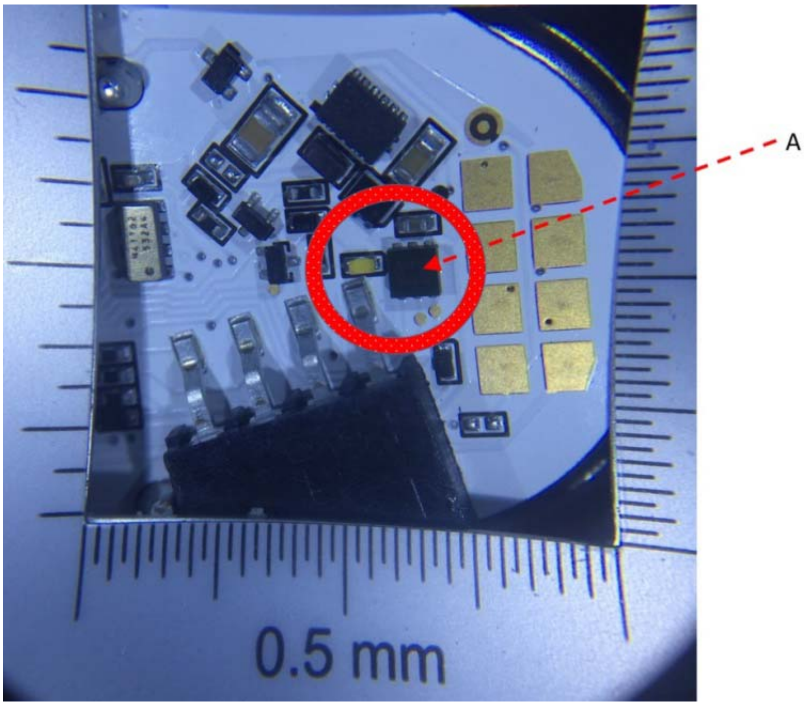

Figure 5 *A close up view of the photosensitive diode (A) underneath the pink silicon material of the Estimote Location Beacon. Note that the red circle is used to add scale to the image.*

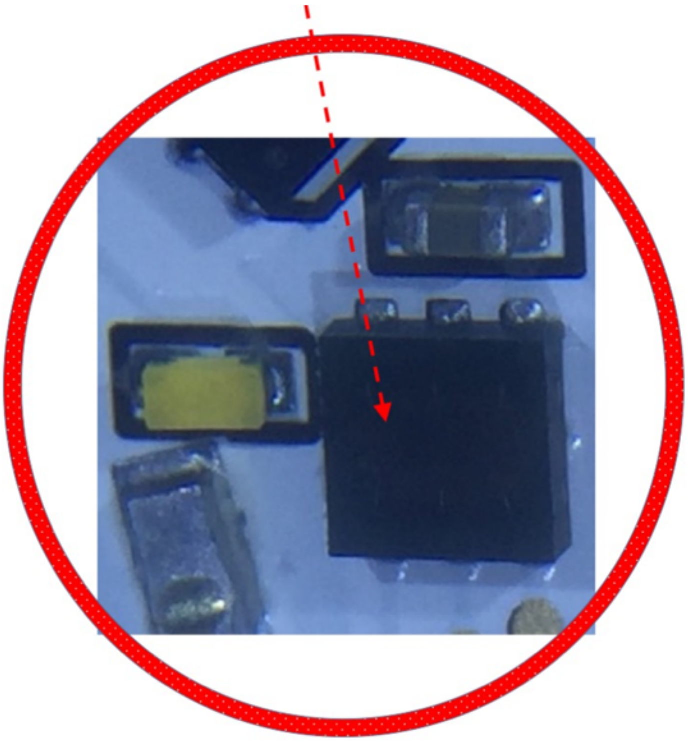

Figure 6 *A close up view of the square photosensitive semiconductor device (shown by the dashed red line) thought to be responsible for the assessment of luminous intensity for the Estimote Location Beacon. The same red circle is used from the previous figure to ensure scale is maintained. N.B. to the top of the device is the very bright yellow LED mentioned earlier.*

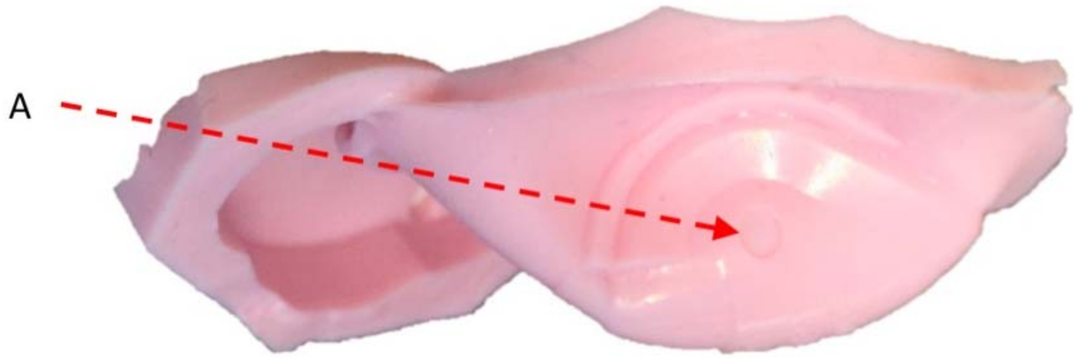

Figure 7 The silicon cover of the Estimote Location Beacon after inversion showing the 7.1 mm² area (A) translucent material covering the photosensitive diode.

2.3 Assessing responsivity of Estimote Location Beacon

The Estimote Location Beacon was positioned in an office environment under a strong desk lamp. The light was switched from Off-to-On twelve times and On-to-Off twelve times for a total of twenty-four data points.

A brief study of the ambient light telemetry packet processing for the Estimote Location Beacon revealed that the variable *ambientLightLevel* is composed of two variables: *ambientLightUpper* and *ambientLightLower* (see Table 3). The ambientLightUpper variable is assigned the upper bit values of the incoming data at location 13 (achieved by masking, i.e. 0b11110000). These upper bit values are then bitwise shifted 4 places to the right. This reduction in magnitude is corrected when the value is squared during the assignment to the ambientLightLevel variable. The ambientLightLower variable is assigned the lower bit values of the incoming data at location 13 (achieved by masking, i.e. 0b00001111). This value is then multiplied by 0.72 and added to the ambientLightUpper value to complete the calculation of the ambientLightLevel variable.

It is observed that the value, 0.72, may be an empirically derived value obtained by the manufacturer of the photosensitive diode to ensure optimal performance.

Table 3 The Estimote Telemetry code from their SDK to process ambient light sensed from the Estimote Location Beacon (Estimote Github & Developers Community, 2016).

```
// ***** AMBIENT LIGHT
// byte 13 => ambient light level RAW_VALUE
// the RAW_VALUE byte is split into two halves
// pow(2, RAW_VALUE_UPPER_HALF) * RAW_VALUE_LOWER_HALF * 0.72 = light level in lux (lx)
var ambientLightUpper = (data.readUInt8(13) & 0b11110000) >> 4;
var ambientLightLower = data.readUInt8(13) & 0b00001111;
var ambientLightLevel = Math.pow(2, ambientLightUpper) * ambientLightLower * 0.72;
```

2.4 Determining the influence of the translucent silicon cover material

The bare photosensitive diode was extracted from the light meter and epoxied to the motherboard of the open Estimote Location Beacon motherboard (see Figure 9). The area of the pink silicon (1mm thick) top cover was excised. The area around the circular translucent material was covered in industrial rubber liquid electrical tape—to block light from being transmitted through the thicker surrounding area (see Figure 8). The centre of the 3mm translucent circle was placed directly over the 3.5 mm x 5 mm active area of the photosensitive diode. This resulted in blocking 17.5 mm^2 - 7.07 mm^2 = 59.6%, of the effective area of the photosensitive diode. (Bottom) The excised 1 mm thick translucent silicon material is placed over the bare photosensitive diode of the Estimote Location Beacon (B). This resulted in blocking 9 mm^2 - 7.07 mm^2 = 21.5% of the effective area of the photosensitive diode.

Twelve measurements were then taken:

1. low light on bare diode from the Light Meter
2. low light on bare diode on the motherboard of the Estimote Location Beacon
3. low light on the standard Light Meter
4. low light on the standard Estimote Location Beacon
5. low light on the bare diode of the Light Meter with the treated translucent silicon cover over it
6. low light on the bare diode of the Estimote Location Beacon with the treated translucent silicon cover over it
7. high light on bare diode from the Light Meter
8. high light on bare diode on the motherboard of the Estimote Location Beacon
9. high light on the standard Light Meter
10. high light on the standard Estimote Location Beacon
11. high light on the bare diode of the Light Meter with the treated translucent silicon cover over it
12. high light on the bare diode of the Estimote Location Beacon with the treated translucent silicon cover over it.

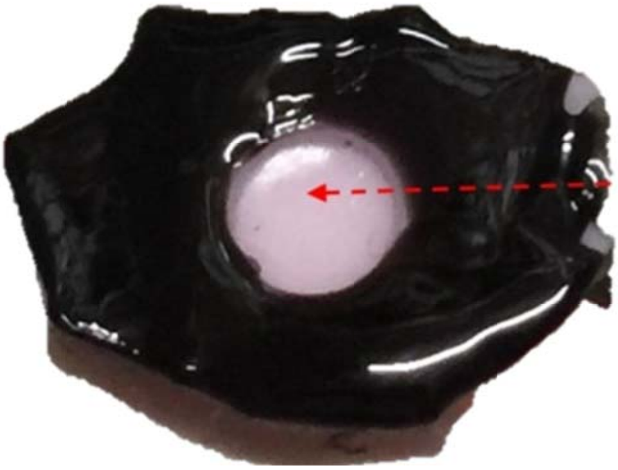

Figure 8 Estimote Location Beacon cover material excised to expose the 3 mm diameter translucent cover over the photosensitive diode. Rubber compound used to separate the thicker silicon casing from central translucent area.

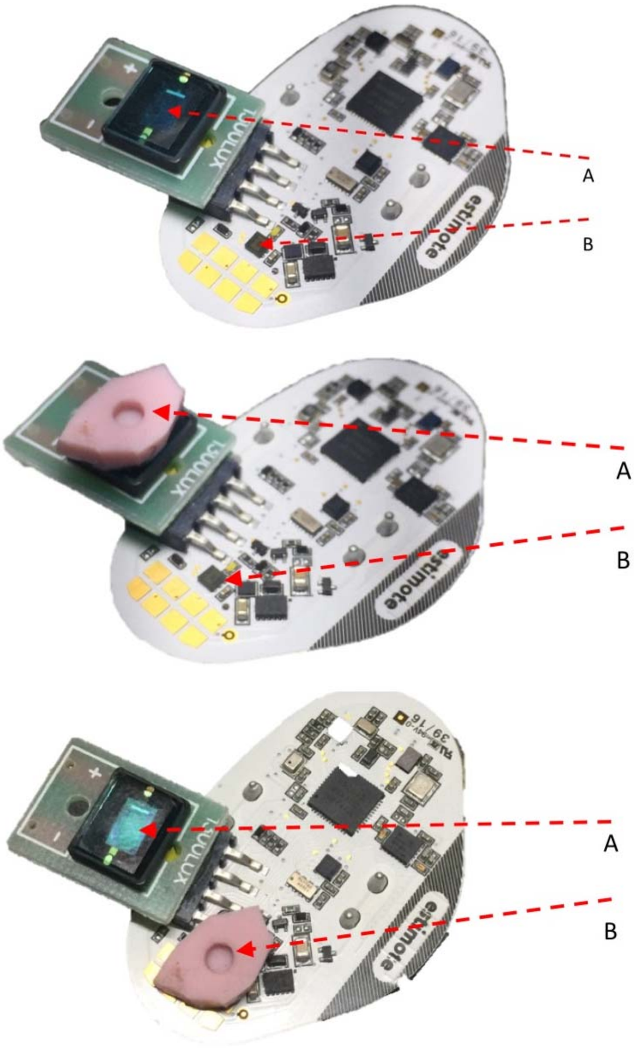

Figure 9 *(Top) The photosensitive diode from the Light Meter is attached to the motherboard of the Estimote Location Beacon. (Middle) The small excised silicon piece is placed over the Light Meter photosensitive diode. (Bottom) The same piece is then placed over the Estimote Location Beacon's photosensitive diode.*

3. Results

3.1 Gathering data from Light Meter and Estimote Location Beacon

The data from the thirteen pairs of observations were collected and simple descriptive statistics calculated (see Table 4). The data was sorted from lowest Lux measurement to highest, and then plotted, using a logarithmic y-axis scale for measurement of Lux. (see Figure 10).

The Light Meter consistently measured higher Lux values than the Estimote Location Beacon. Two characteristic functions (see Figure 11) were derived for each plot and shown below as Equation 1 and Equation 2.

$$Equation\ 1\ \text{-}\ Light\ Meter\ (Lux) = 29.0509e^{0.5577x}$$

$$Equation\ 2\ \text{-}Estimote\ Location\ Beacon\ (Lux) = 13.8252e^{0.5499x}$$

Table 4 Results of data collection. Thirteen locations were randomly chosen to assess both the Estimote Location Beacon and the Light Meter. The data were ordered from the lowest Lux measure to the highest (soft indoor lighting to bright midday sun outdoors). The mean and standard deviation were included.

Location #	Light Meter (Lux)	Estimote Location Beacon (Lux)
1	92	35
2	122	59
3	133	97
4	160	64
5	396	182
6	1040	321
7	1375	571
8	1704	1509
9	4100	1411
10	5500	2995
11	5610	1739
12	43700	16035
13	90500	47923
Mean	11879	5611
Standard Deviation	26379	13420

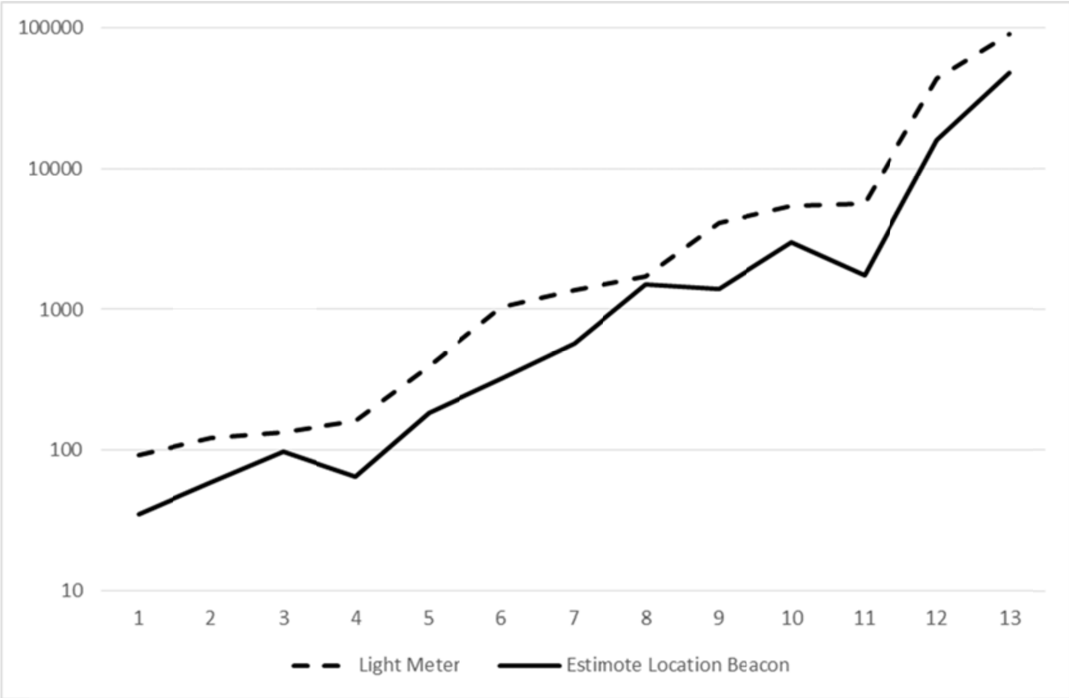

Figure 10 *Initial plot of the 13 data points. Note that the y-axis is logarithmic (Lux). Also note that the Estimote Location Beacon results are all lower than the Light Meter. The x-axis represents the different locations, in increasing order of Lux.*

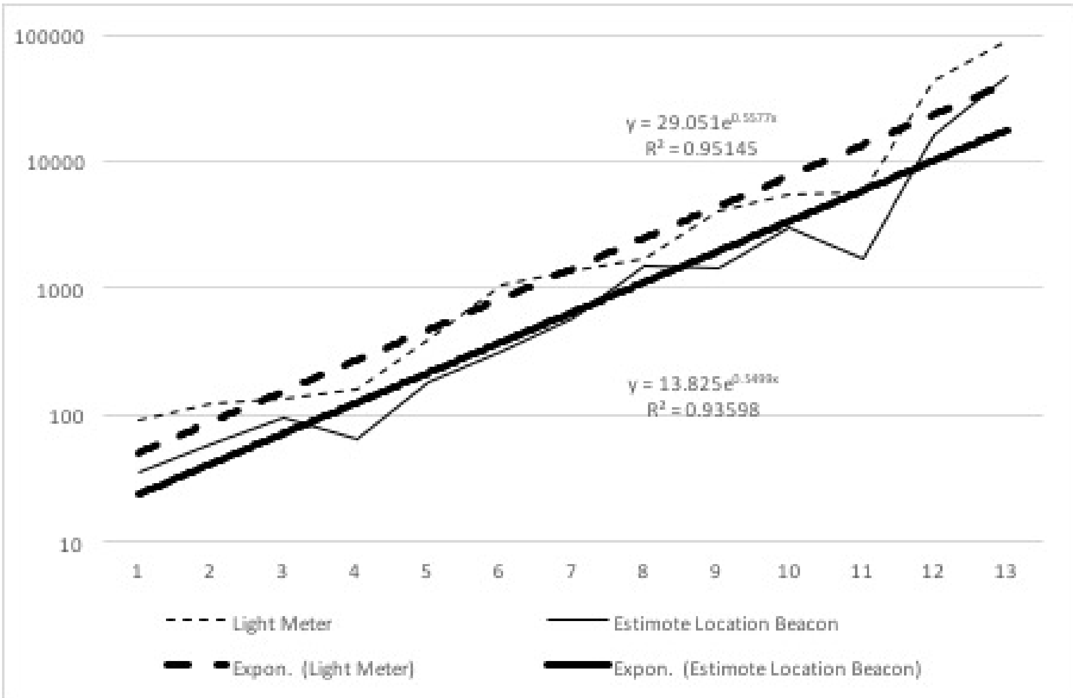

Figure 11 *Plot of the two exponential characteristic functions derived to fit the data. Note that both functions are highly representative of variation in the data as shown by the two high* R^2 *values.*

An adjustment coefficient, to bring the Estimote Location Beacon data into alignment with the Light data, was calculated as shown below. Constants were handled separately to allow for the ease of calculation as shown in Table 5. The result, a factor of 2.1178, is shown in Equation 13.

Table 5 Constants used in calculation of adjustment coefficient.

$c_1 = 13.8252$	$c_2 = 29.0509$
$c_3 = 0.5499$	$c_4 = 0.5577$
$c_5 = \log c_1 = 2.6265$	$c_6 = \log c_2 = 3.3691$
$c_7 = c_6 - c_5 = 0.7426$	$c_8 = c_4 - c_3 = 0.0078$
$c_9 = c_7 + c_8 = 0.7504$	

Equation 3 - $c_1 e^{c_3 x}\theta = c_2 e^{c_4 x}$

Equation 4 - $\theta = \frac{c_2 e^{c_4 x}}{c_1 e^{c_3 x}}$

Equation 5 - $\log \theta = \log \frac{c_2 e^{c_4 x}}{c_1 e^{c_3 x}}$

Equation 6 - $\log \theta = \log c_2 e^{c_4 x} - \log c_1 e^{c_3 x}$

Equation 7 - $\log \theta = \log c_2 + \log e^{c_4 x} - [\log c_1 + \log e^{c_3 x}]$

Equation 8 - $\log \theta = c_6 + c_4 x - [c_5 + c_3 x]$

Equation 9 - $\log \theta = c_7 + (c_4 x - c_3 x)$

Equation 10 - $\log \theta = c_7 + c_8 x$, *let x=1*

Equation 11 - $\log \theta = c_9$

Equation 12 - $e^{\log \theta} = e^{c_9}$, *substitute from constants table*

Equation 13 - $\theta = 2.1178$

The data as shown in Figure 10 was then replotted after multiplying the Estimote Location Beacon values by the adjustment coefficient (see Figure 12).

Figure 12 Second plot of the 13 data points after multiplying the Estimote Location Beacon results by the correction coefficient (2.1178).

New characteristic functions were derived for the adjusted data and are showing in Figure 13. Note that the coefficient to the exponential term is approximately equal.

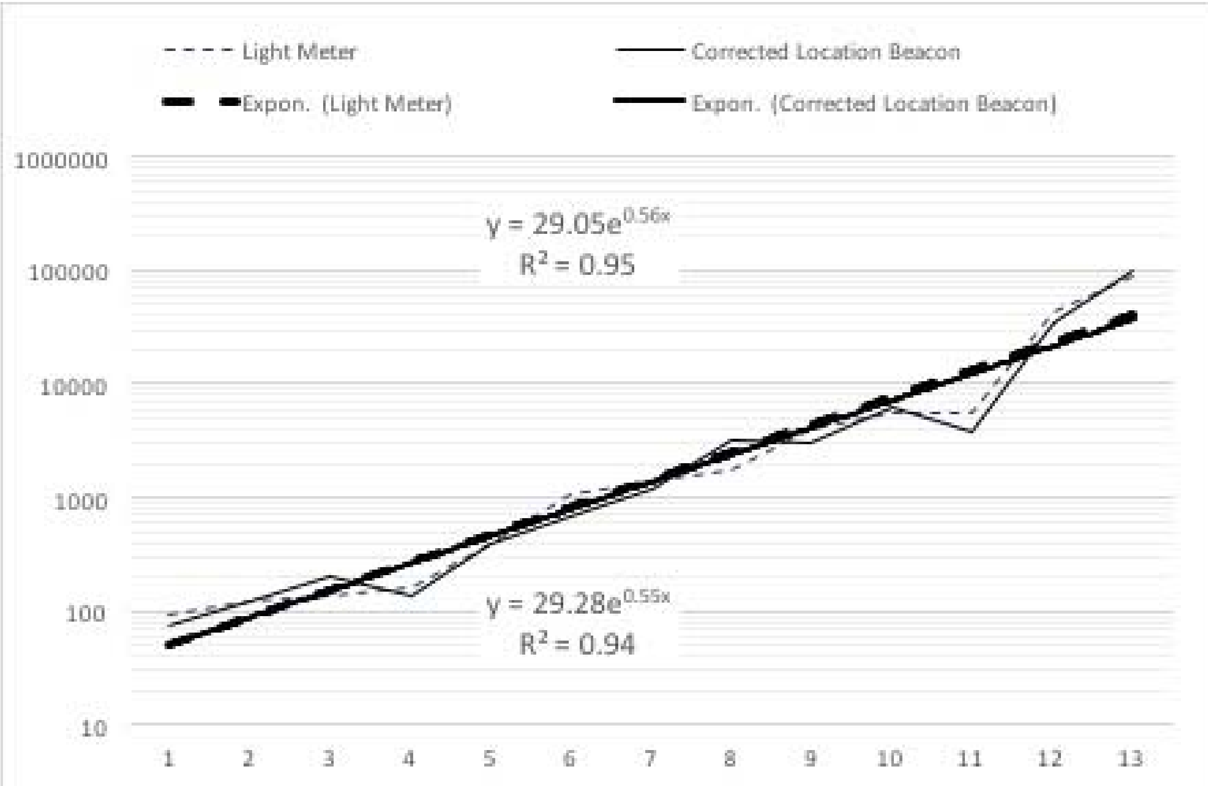

Figure 13 Third plot of the 13 data points after adding characteristic functions based on corrected data.

3.2 Assessing responsivity of Estimote Location Beacon

The Estimote Location Beacon iPhone-based app showed that the change in external light input was transmitted through the photosensitive diode, then the Estimote Location Beacon motherboard, then through the Bluetooth communications channel into the iPhone. This indirect method of reading the data resulted in an average of 4.8 seconds for the change to register (see Figure 14). If the photosensitive diode was examined at the board level using direct connections the responsivity to light changes would be an order of magnitude better than is measured here in this experiment. This is due to the amount of overhead processing use by Estimote to produce a multi-sensor comprehensive assessment of the beacon's surroundings.

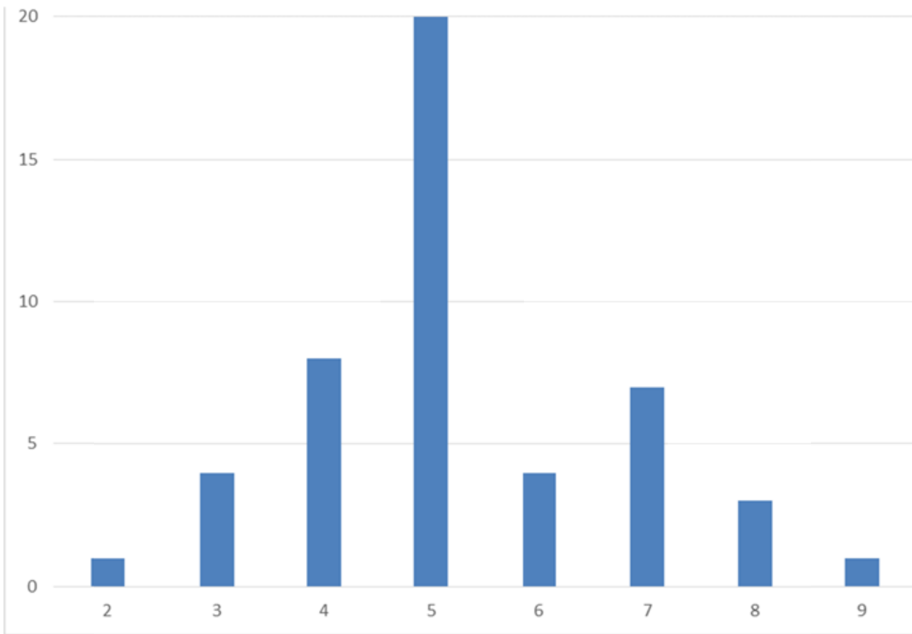

Figure 14 Histogram showing temporal responsiveness of the Estimote Location Beacon Ambient Light update rate. The y-axis shows the number of experimental results. The x-axis shows, in seconds, the amount of time it took for the Estimote app to register that the ambient light photosensitive diode had been exposed to a change from 128 Lux to 0 Lux, in a dark room. Mean = 4.8, Standard Deviation = 1.4, Median = 4.4, Standard Error = 0.2.

3.3 Determining the influence of the translucent silicon cover material

The bare photosensitive diodes from both Light Meter and Estimote Location Beacon were exposed to the two light sources (see Table 6). Standard readings with the diode reinstalled in its housing were also assessed. The actual 3 mm diameter translucent silicon section was overlaid on the bare diodes as a third test. The addition of the diffuser over the Light Meter bare diode resulted in an average reduction of 50% Lux measurement. The repackaging of the bare diode into the Estimote Location Beacon silicon housing resulted in an average 93% Lux measurement reduction. The small silicon piece over the Light Meter diode resulted in 94% Lux measurement reduction. The same piece over the

Estimote Location Beacon diode resulted in an average of 84.5% Lux measurement reduction.

Table 6 Results of experiment to determine effect of 1 mm thick translucent silicon cover over sensor. Two light sources were used. The bare photosensitive diodes from both Light Meter and Estimote Location Beacon were exposed to the light sources. Standard readings with the diode reinstalled in its housing were also assessed. The actual 3 mm diameter translucent silicon section was overlaid on the bare diodes as a third test.

Lux		Bare diode	Standard	With silicon cover	% Loss due to housing	% Loss due to translucent silicon over sensor
Low	Light meter	230	124	14.4	46%	94%
	Beacon	145	8	24	94%	83%
High	Light meter	20600	9910	1270	52%	94%
	Beacon	11335	852	1566	92%	86%

4. Discussion

4.1 Gathering data from Light Meter and Estimote Location Beacon

Prior to data collection it was assumed that the silicon body of the Estimote Location Beacon would hamper the performance of the photosensitive diode used on the beacon's motherboard. However, as demonstrated by the subsequent data analysis, the diode performance was equivalent to a standard Light Meter.

4.2 Assessing responsivity of Estimote Location Beacon

The ambient light sensing capability of the Estimote Location Beacon appears to be designed for non-real time applications. It is probably best considered to use numerous beacons together over a larger area and to write software which characterises the light into discrete (not continuous data) groupings. For example, define five groups: near-dark, dim, normal, bright, and extreme.

An obvious next step in assessing responsivity would be to connect directly to the photosensitive diode on the board. Bypassing the higher level firmware and connectivity required for the Estimote SDK to function would enable this board-level connection to reveal the diode's true responsivity.

Perhaps collaboration with Estimote, in a research capacity, would produce a Beacon with more highly capable light sensing. With some modifications to the SDK, this modified Beacon would perform more effectively in a Search and Rescue operation where subtle changes in light might be important.

4.3 Determining the influence of the translucent silicon cover material

Exposing the bare photosensitive diodes directly to the test light sources produced a baseline assessment of the raw performance of the diode. Comparing this data to the data acquired from the sensor in their standard setting revealed the amount of light energy lost to the housing material. Although the light meter lost approximately 45% of light energy to the housing material, the Estimote Location Beacon housing material (pink silicon) blocked approximately twice that (~90%).

It can be assumed that the manufacturers of both the Light Meter and the Estimote Location Beacon are aware of this and have calibrated both devices to compensate for this loss. The interpretation of light loss due to the placement of the small pink silicon over the sensors is more difficult to articulate. Perhaps this data can be used at a future point when producing bespoke versions of the Estimote Location Beacons.

The Estimote Location Beacon does not appear to be designed for scientific and technological applications. However, with some minor physical changes and related SDK alterations, perhaps they could add value in new and exciting applications.

5. Conclusions

With the information acquired in this study specific applications and experimental testing using the Estimote Location Beacon ambient light sensor can be completed with confidence. More specifically, the responsiveness of the ambient light sensor will guide us in the placement of the beacon. Initial applications for this particular sensor data was that a person's shadow, as they walk by a beacon, might be enough of a stimulus to trigger an ambient light change, as measured in Lux. However, given the responsiveness it may be more prudent to deploy the beacons next to a strong light source to determine when it is switched on.

This is the first of a series of five Technical Notes, each focussed on understanding the performance of each of the five sensors on the Estimote Location Beacon. Using DST Group's substantial science and technology skills and facilities to assess and potentially modify these devices, a new research capability for clients can be offered.

References

Estimote Github & Developers Community. (2016, 12 11). *estimote-specs/estimote-telemetry.js at master - Estimote/estimote-specs . GitHub* . Retrieved from GitHub, Inc: https://github.com/Estimote/estimote-specs/blob/master/estimote-telemetry.js

Krzych, J., & Kostka, Ł. (2016, 12 11). *Estimote Telemetry - Estimote Developer*. Retrieved from Estimote: http://developer.estimote.com/sensors/estimote-telemetry/

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Appendix – Light Meter Specifications

Note: The light meter instruction manual included here has been scanned and contains some typographical errors. Also, note that the product specification sheet for the Estimote Location Beacon photosensitive diode is not included. This is intentional as it is beyond the scope of this paper. More detailed information, such as this product specification sheet, is more appropriately included in a more rigorous DST Group Technical Report.

INSTRUCTION MANUAL
Light Meter

TABLET OF CONTENTS

1. FEATURES

- 3 –1/2digit LCD display with low battery indication.
- Easy to use with single function switch operating, pocket size and light weight.
- Light measuring levers ranging from 0.01 lux to 50,000 lux.
- 2000 lux: reading x 10; 50,000lux: reading x 100

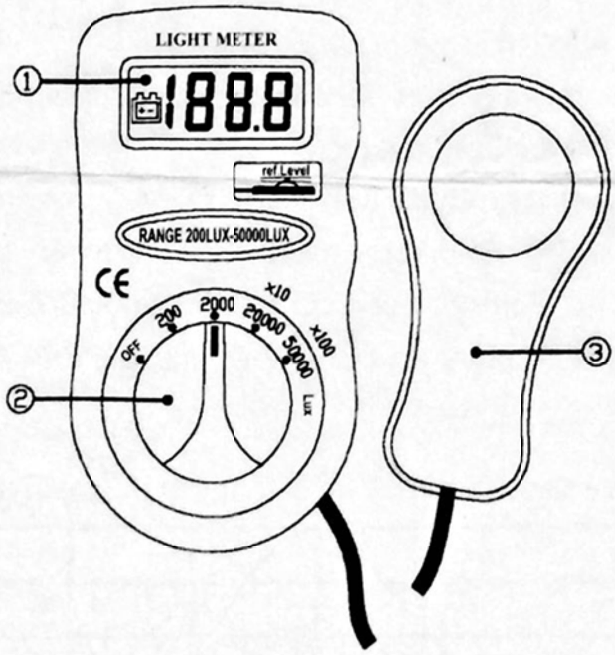
2. SPECIFICATIONS

Display: 1999 counts LCD display with low battery indication.
Over-range: "1" mark indication.
Low battery indication: The "BAT" is displayed when the battery voltage drops below the operating level.
Measurement rate: 1.5 times per second, nominal.
Storage temperature: -10℃ to 60℃ (14℉ to 140℉) at<80% relative humidity
Power: One standard 12V, A23 battery.
Photo Detector Dimensions: 115 x 60 x 27mm
Dimensions: 188 x 64.5 x 24.5mm
Weight: 160g

Light

Measuring Range: 200, 2000, 20,000lux (20,000lux range reading x 10) and 50,000lux (50,000lux range reading x 100)
Overrate Display: Highest digit of "1" is displayed.
Accuracy: ±5%rdg + 10 dgts (<10,000 lux)
±10%rdg + 10 dgts (>10,000 lux)
(calibrated to standard incandescent lam,2856 k).
Repeatability:± 2%.
Temperature Characteristic: ±0.1%/℃.
Photo detector: One silicon photo diode with filter.

3. PANEL DESCRIPTION

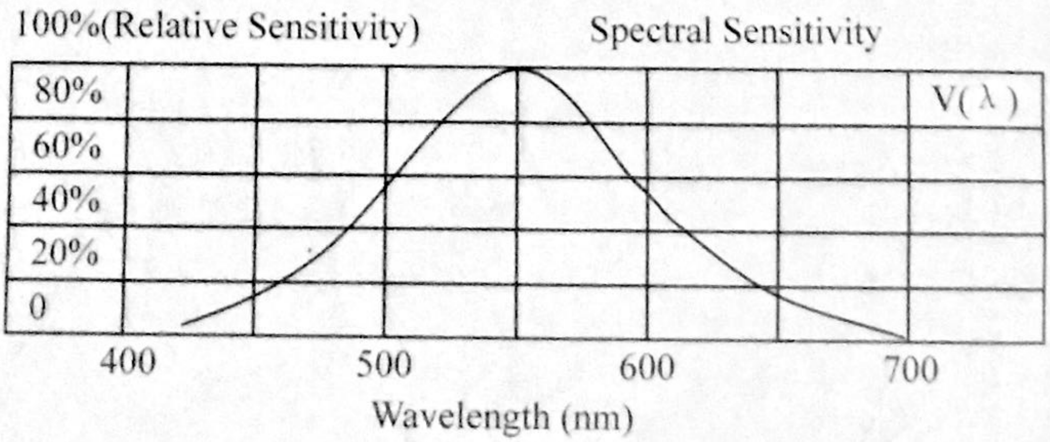


1. LCD display: 3 – 1/2digit LCD display with low battery "BAT" indication.
2. Power / Function / Range Switch: Turn power on (or off) and select measurement function and ranges.
3. Photo Detector: Long life silicon photo diode inside.

4. OPERATING INSTRUCTION

Measuring Light

1. Turn the Power/function/range Switch to select the "lux" scale and set the range to desired ("lux", "x10 lux" or x 100 lux) range.
2. Remove the photo detector to light source in a horizontal position.
3. Read the illuminance nominal from the LCD display.
4. Over-range: If the instrument only display one "1" in the M.S.D. the input signal is too strong, and a higher range should be selected.
5. When the measurement is completed. Replace the photo detector from the light source.
6. Spectral sensitivity characteristic: To the detector, the applied photo diode with filters makes the spectral sensitivity characteristic almost meet C.I.E. (International Commission on Illumination) photopia curve V (λ) as the following chart described.



7. Recommended Illumination:

Locations	Lux
*Office	
Conference, Reception room.	200 ~ 750
Clerical work	700 ~ 1,500
Typing drafting	1000 ~ 2,000
*Factory	
Packing work, Entrance passage	150 ~ 300
Visual work at production line	300 ~ 750
Inspection work	750 ~ 1,500
Electronic parts assembly line	1500 ~ 3,000
*Hotel	
Public room. Cloakroom	100 ~ 200
Reception, Cashier	200 ~ 1,000
*Store	
Indoors Stairs Corridor	150 ~ 200
Show window, Packing table	750 ~ 1,500
Forefront of show window	1500 ~ 3,000
*Hospital	
Sickroom, Warehouse	100 ~ 200
Medical Examination room	300 ~ 750
Operating room	
Emergency Treatment	750 ~ 1,500
*School	
Auditorium, Indoor Gymnasium	100 ~ 300
Class room	200 ~ 750
Laboratory Library Drafting room	500 ~ 1,500

5. BATTERY REPLACEMENT

If the sign "BAT" appears on the LCD display, it indicates that the battery should be replaced. Remove screws on the back cover and open the case. Replace the exhausted battery with new battery.

(1 x 12V battery A23 or equivalent)

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19. ABSTRACT

The Estimote Location Beacon™ is the latest addition to the Hybrid.Beacon DST Group project. This project uses inexpensive commercial components to assess the potential for increased situational awareness in tactical scenarios. The ability of the Estimote Location Beacon to generate, and participate in a Bluetooth-based Mesh Network, along with an amazing array of on-board sensors, makes it an area of high potential for innovation. This Technical Note will focus on one of the Beacon's sensors, its ambient light capability. The next Technical Note in this series will focus on the magnetometer.