Properties of two light sensors

Timo Paukku Dinnesen (timo@daimi.au.dk) University of Aarhus
Aabogade 34 8200 Aarhus N, Denmark

January 10, 2006

1 Introduction

Many projects using the LEGO Mindstorms RCX employ light sensors for different purposes. These purposes range from the classical line follower[1] and light follower[2] to IR-Radars[3]

Currently two kind of sensors are available to most people involved in RCX Robotics. The standard LEGO light sensor that comes with the LEGO Robotics Invention System kit, and a simple homebuilt sensor using a *light dependent resistor*(LDR).

This appendix will describe some advantages and disadvantages of each sensor.

2 Description of the sensors

2.1 The LEGO light sensor

The LEGO sensor comes with the LEGO Robotics Invention System kit. It can be used in active mode and passive mode. In the active mode the sensor receives power from the RCX. This power is used to drive the electronics inside the sensor and is also used to power a small but strong light placed on the sensor. In passive mode the sensor does probably not work as intended but its output values can still be read and they do change depending on the light shining on the sensor. A detailed description of the internals of the sensor can be found at the MindStorms RCX Sensor Input Page[Gas]

[1] A robot that follows a line drawn on a surface.

[2] For example a robot that drives toward a flashlight.

[3] At www.robotthoughs.com there is a topic containing several robots using IR and light sensors as radars.

Figure 1: The standard LEGO light sensor.

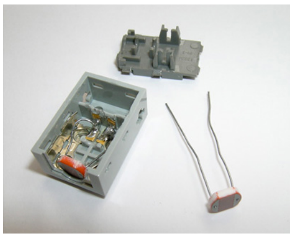

Figure 2: The disassembled simple LDR light sensor and an extra LDR to the lower right.

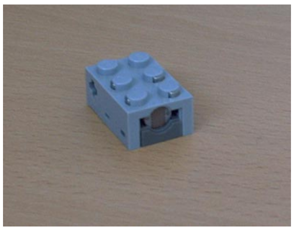

Figure 3: The finished simple LDR light sensor.

2.2 The simple LDR sensor

The simple LDR sensor is simply a light dependent resistor that is connected to an input port on the RCX. To make the sensor look better and seamlessly connect to other LEGO bricks the LDR is often put inside hollowed out LEGO bricks. The simple internals can be seen on figure 2. The finished sensor, here inserted into a broken touch sensor can be seen on figure 3

3 Measuring light

Measuring the intensity of light is a complex matter because of the many properties of light: wavelength, distance from source, measuring where it hits or where it comes from etc. Several different units can be used for these measurements depending on the way the experiments are carried out.

In this appendix the unit *lux* will be used. A simple description of lux is that it is a unit used to measure how much light hits a surface of a size of one square meter.

It's common practice to use the lux unit to measure for example work environments. Table 1 give an example of the typical lux values found in different areas,[Opt].

Natural light	Lux
Bright sun	50.000 - 100.000
Hazy day	25.000 - 50.000
Cloudy bright	10.000 - 25.000
Cloudy dull	2000 - 10.000
Very dull	100 - 2000
Sunset	1-100
Full moon	0.01 - 0.2
Starlight	0.001 - 0.001
Artificial light	**Lux**
Operating room	5000 - 10.000
Shop windows	1000 - 5000
Drawing office	300-500
Office	200-300
Living room	50-200
Corridors	50-100
Good street light	20
Poor street light	0.1

Table 1: Examples of typical lux values

As it can be seen the human eye can handle a very wide spectrum of light conditions. Studies show that the human eye senses light in a logarithmic way and, because of this, can function very well in both dark and in very bright environments,[Wik].

4 Light sensitivity

The sensors were exposed to different kinds of light sources to see which raw values were produced, and how wide the range of outputs were. The sensors were put next to each other and next to them the light was also measured with a light meter, which was set to measure light in *lux*. The exact readings can be found in table 7 in the end of this appendix. Figure 4 shows a more comprehensible graphical view of the data.

Because the human eye senses light in a logarithmic way the graph has been created with a logarithmic x axis. Because of the logarithmic x axis the readings for 0 lux have not been included in the graph.

The graph shows that the active LEGO sensor shows a somewhat linear behavior compared to the way a human senses light changes. The passive LEGO sensor does not really give any useful values even though a closer

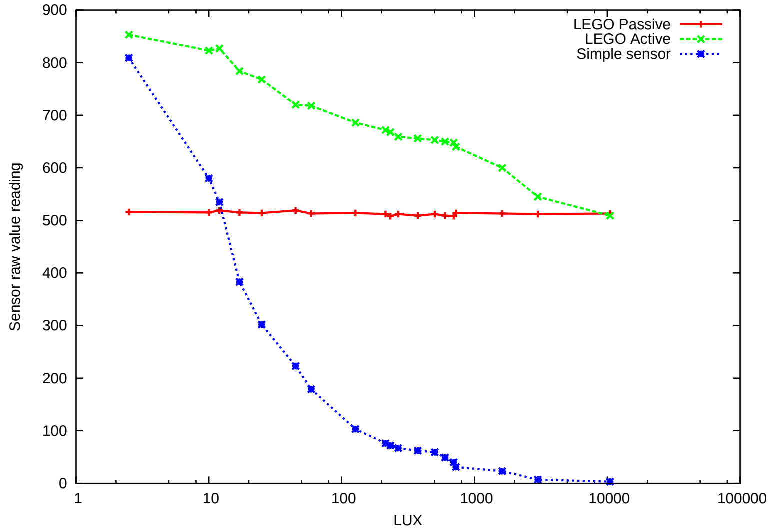

Figure 4: Raw values from the sensors under different light conditions.

look at the measurements show that they tend to get lower as the brightness increases. The simple sensor does not at all behave in a linear way, but it has a much larger span of output values than the LEGO sensor. This could mean that the simple sensor can sense much smaller changes in light, but this is not something that can be concluded now because the larger span does not automatically mean a more sensitive sensor.

4.1 Operation under different light conditions

The choice of sensor might very well depend on where it should be used. This section deal with the sensitivity in different light conditions. Figure 5 shows how the number of output values are "dedicated" to different light conditions. The areas are defined as:

- **Outside**
  This range of light is usually found outdoors with the sun shining. On a cloudy day the average light intensity is 2000 LUX and direct sunlight may be up to 100.000 LUX
- **Bright**
  This range is composed of bright light in the range of 500-3000 LUX. It could for example be the light cone of a flashlight.
- **Normal**
  This range is from 50 to 500 LUX. Everyday examples would be the light in a living room up to good reading light in an office.

- **Darkness**
  The range of 0 to 50 LUX. This could for example be an experimental setting in a dark room. It is definitely not the usual work environment.

Figure 5 was done by dividing the number of raw values available in the subintervals of each light condition with the total number of possible raw values for each sensor. For example the LEGO sensor outputs values from 509 to 862 and thus uses an interval of 353 different values when going from complete darkness to outside sunlight. When used in *Darkness* the sensor reports values from 862 down to 720. This subinterval is thus 142 values "wide" and represents 40% of the total interval of values.[4] All the four subintervals are stacked in the figure.

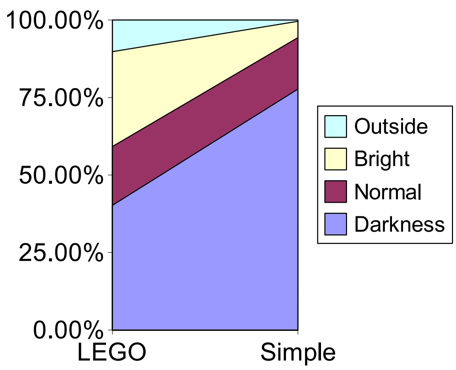

Figure 5: The percentage of values dedicated to different light conditions.

4.1.1 The LEGO sensor

The LEGO sensor has a fair amount of output values dedicated to each light condition, compared to the total number of values. It looks like the sensor was built to work in all kinds of light conditions. The sensitivity to bright light covers a much broader span than the simple sensor. This could mean that the LEGO sensor is good at working in normal light conditions doing tasks where it has to detect bright light.

4.1.2 The simple sensor

The simple sensor has the majority of its output values in the dark area. This could mean that it will be able to detect very small light changes in dark environments. It's uses outside might not be very good because only a very small interval of values can be detected if the ambient light is very strong.

[4] $142/353 \approx 0.40 = 40\%$

Type of light	LEGO not active	LEGO active	Simple	Simple with blind
Flashlight	10 cm	2 m	3 m	3 m
LEGO lamp	10 cm	1.5 m	1m	1 m

Table 2: Sensitivity to light changes in a dark room (0.25 LUX)

Type of light	LEGO not active	LEGO active	Simple	Simple with blind
Flashlight	10 cm	1 m	1 m	4.5 m
LEGO lamp	10 cm	1 m	10cm	50cm

Table 3: Sensitivity to light changes in a normally lit room (225 LUX)

Type of light	LEGO not active	LEGO active	Simple	Simple with blind
Flashlight	10 cm	10 cm	10 cm	10 cm
LEGO lamp	0 cm	0 cm	0 cm	0 cm

Table 4: Sensitivity to light changes in a very lit room (4000 LUX)

4.2 Practical tests

To further investigate the properties of the sensors in different light conditions a couple of experiments were done. The simple sensor has a broader output range in values which might make it better at detecting small light changes. On the other hand the LEGO sensor may be better at this because of the built in electronics.

The following experiment was done in different light conditions. Both sensor types were attached to the same RCX. The program in the RCX monitored the sensors and did an automatic calibration. When the sensors detect light that is stronger than the ambient light they reported this by turning on an output port. On these were mounted small lamps so that it was possible to see when a sensor would detect a light change.

Two different types of lamps were used to direct light at the sensors. The fist one was a small flashlight and the other was a standard LEGO lamp connected to an RCX with fresh batteries. The flashlight was chosen because many LEGO league projects,[Fir], involve a flashlight to "remote control" an RCX, and the LEGO lamp was chosen because it is the obvious choice if one wants to put a light source onto an RCX.

The tests were done to determine the distances at which the sensors were able to detect light changes. Tables 2, 3 and 4 show the distances at which the sensors reported the changes correctly. During the tests it was discovered that the ambient light had a very large effect on the simple sensor. To minimize this effect the sensor was also tested with a blind, consisting of a LEGO brick with a hole in it, placed in front of the sensor. An example of this can be seen in figure 6

Figure 6: The simple sensor fitted with a LEGO brick to decrease the influence of ambient light.

4.3 Conclusion on light sensitivity

The tests clearly show that both sensors work best in dark environments. In strong light their uses are very limited. An interesting result is that the simple sensor is very good at detecting the flashlight at very long distances, but when the small LEGO light is used the active LEGO sensor is much better. Some descriptions,[Pro], of the internals of the LEGO sensor conclude that some of the electronics are there to enhance the functionality in bright areas. This is probably why the LEGO sensor is much better at detecting the small LEGO light in the normally lit room.

In a normally lit room it helps very much to use the blind on the simple sensor. A detection range of 4.5 m was much better than what any of the other sensor setups could produce.

5 Color recognition

The sensors does not distinguish between colors as they only report the intensity of light, and thus only function in the so called gray scale. In many projects it is often nice to be able to use colored areas to control navigation of for example robots. Since not all colors reflect the same amount of light the sensors should be able to distinguish between some colors. To test how the two sensors performed the following experiment was done.

5.1 Experiment and results

The sensors were at all times connected to the same RCX so that all measurements could be done at the same time. The sensors were placed in a distance of 0.5 cm away from colored pieces of cardboard. Also the effects of disturbing ambient light was measured. This was done by blocking the ambient light by placing different objects randomly around the sensors and noticing how this affected the output values. The results can be seen in table 5 which shows readings from the LEGO sensor in both modes and the readings from the simple sensor.

Sensor	White	Yellow	Orange	Green	Magenta	Brown	Blue	Red	Black	Ambient influence
Passive	518	517	518	518	518	517	518	518	518	1-2
Active	686	688	686	729	698	713	742	729	760	10-12
Simple	209	229	252	286	288	335	379	520	760	400-500

Table 5: Sensor values when pointed at different colors.

A second test was done to measure the performance when ambient light had no effect. Each of the sensors where enclosed in a box of black LEGO bricks. The cardboard was still 0.5 cm. away. For this test the simple sensor had help from a simple LEGO light mounted next to it in a way so that the light could not shine directly into the sensor. The light was powered from the RCX output port and was not very strong compared to the LEGO sensor's light. The LEGO sensor did not need this since it was set to active and thus had it's own internal light source turned on. Results for different colors can be seen in table 6.

Sensor	White	Yellow	Orange	Green	Magenta	Brown	Blue	Red	Black
LEGO	699	702	698	743	710	726	758	729	795
Simple	301	308	318	428	329	388	468	308	598

Table 6: Sensor color measurements without influence from ambient light.

The first experiment reveals that the simple sensor and the passive LEGO sensor are almost useless at this setting. The LEGO sensor is not sensitive enough when passive and does not produce different values no matter what color it is placed on. The simple sensor is so heavily influenced by ambient light that it is almost unusable. Only in a very controlled environment it might be possible to distinguish between black and white.

When the LEGO sensor is used in active mode, the results are very good. This might be because the built in light on the LEGO is very strong and therefore ambient light does not change the values much. In this set up it was possible to distinguish between 5 different colors. For example white, magenta, green, blue and black.

The last experiment shows that in a perfectly controlled environment the sensors can distinguish between more colors. Since they only measure in gray scale some colors still give almost the same raw values. This last scenario might be usable in special setups, but would usually be almost impossible to achieve.

5.2 Conclusion on color recognition

The LEGO sensor is clearly the best sensor for use if one wants to distinguish between colors. Only when ambient light influence is at a minimum or perhaps if one fitted a strong light to the simple sensor it might be able to do the same. Since the LEGO sensor is very good it would seem a bit pointless to do so. It might be possible to distinguish between even more colors if one can find the right color/material combination. This test was intended to show which sensor was best and should not be considered a final conclusion on how many colors it is possible to distinguish.

6 Conclusion

The two sensors are very different and both have their advantages and disadvantages. The simple sensor works best in low light conditions and when detecting light at long distances is important. When working with the simple sensor one should be aware of its non linear way of working. Also the LDR in the simple sensor comes in many variations. Other LDR's may not give the same output values or may even be working in a linear fashion.

The LEGO sensor is clearly easier to use and is also better at detecting light in normally lit environments. The LEGO sensor only has its good properties when used in active mode, and it could lead to problems that the sensor light is very strong. For example if one does not want extra light introduced into the environment. The strong light is also the strength of the LEGO sensor, because it makes the sensor very good at recognizing colors.

The choice of sensor could also depend on many other factors. For example it is possible to use the LEGO light sensor combined with a touch sensor on the same RCX input. This is not possible with the simple LDR sensor used in this appendix. It can probably be done by adding an extra normal resistor to the sensor. This would however decrease the large interval of output values.

The simple sensor has a much larger "window" for light and can detect changes at much wider angle than the LEGO sensor. This all depends on how one choses to build the simple sensor, and on how one would place the sensor in the experiment, but could be a reason for choosing the simple sensor.

A general thing to remember when using the sensors is that they function best in darker environments, and that this can be utilized easily because humans have good vision even in darker areas. For example an experiment done at 50-100 lux would make the sensor outputs much better, compared to what they would be in a room with 300-500 lux, and this difference in ambient light would not mean anything to a human observer.

7 Raw data

LUX	LEGO passive	LEGO active	Simple
0	519	862	991
2.5	516	853	809
10	515	823	580
12	519	827	535
17	515	784	383
25	514	768	302
45	519	720	223
59	513	718	179
127	514	686	103
214	512	672	76
233	508	668	72
267	512	659	67
374	509	656	62
502	512	653	59
600	509	650	49
697	508	648	40
725	514	640	31
1619	513	600	23
3000	512	545	7
10500	513	509	3

Table 7: These data were used to create the graphs.

References

[Fir] `http://www.firstlegoleague.org`.

[Gas] Michael Gasperi. `http://www.plazaearth.com/usr/gasperi/lego.htm`. MindStorms RCX Sensor Input Page.

[Opt] Electro Optical. `http://www.electro-optical.com/whitepapers/candela.htm`. Most of the typical lux readings can also be found scattered around on different webpages at the Danish Working Environment Authority, `http://www.at.dk`.

[Pro] Kekoa Proudfoot. `http://graphics.stanford.edu/~kekoa/rcx/`.

[Wik] `http://en.wikipedia.org/wiki/Weber-Fechner_Law`. Wikipedia entry describing the relationship between the physical magnitudes of stimuli and human perception of the intensity of stimuli.