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Parallax Laser Range Finder (#28044)

Designed in conjunction with Grand Idea Studio (www.grandideastudio.com), the Parallax Laser Range Finder (LRF) Module is a distance-measuring instrument that uses laser technology to calculate the distance to a targeted object. The design uses a multicore Propeller microcontroller, CMOS camera, and laser diode to create a low-cost laser range finder. Distance to a targeted object is calculated by optical triangulation using simple trigonometry between the centroid of laser light, camera, and object.

Features

- Optimal measurement range of 6–48 inches (15–122 cm) with an accuracy error <5%, average 3%
- Maximum object detection distance of ~8 feet (2.54 meters)
- Range finding sample rate of 5 Hz
- Compact module with integrated CMOS camera and laser diode
- Single row, 4-pin, 0.1” header for easy connection to a host system
- All engineering materials released as open source under a Creative Commons license; see page 23

Key Specifications

- Power requirements: 5 VDC @ 150 mA
- Communication: Asynchronous serial 300–115,200 baud with automatic baud rate detection
- Operating temperature: 32 to 122 °F (0 to 50 °C)
- Dimensions: 3.95" W x 1.55" H x 0.67" D (10.05 W x 3.95 H x 1.7 D cm)

Application Ideas

- Distance or liquid level measurements
- Object detection and/or avoidance
- Item counting

Parallax Laser Range Finder
DANGER
LASER RADIATION
AVOID DIRECT EYE EXPOSURE
DIODE LASER
3 mW MAX OUTPUT at 635 nm
CLASS IIIa LASER PRODUCT
GND
VCC
SOUT
SIN

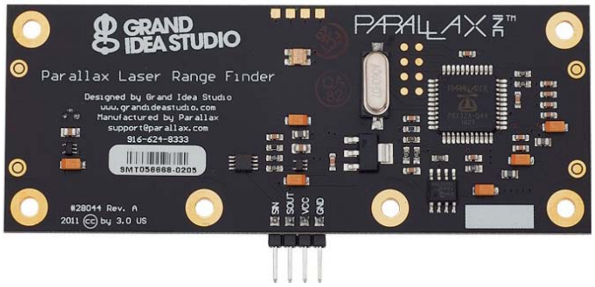


Table of Contents

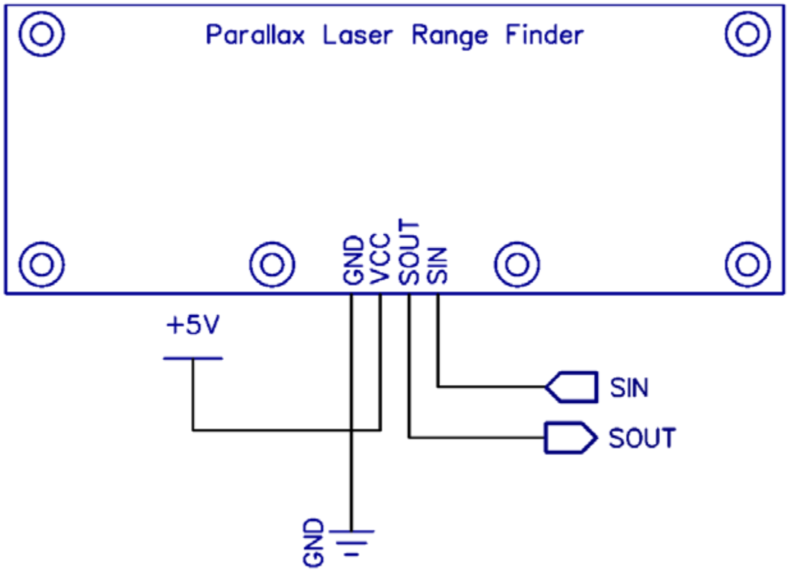
Connections

The LRF Module interfaces to any host microcontroller or computer system using only four connections (GND, VCC, SOUT, SIN).

Pin	Name	Type	Function
1	GND	G	System ground. Connect to power supply's ground (GND) terminal.
2	VCC	P	System power. 5 VDC input.
3	SOUT	O	Serial output ***to*** host. 5 V TTL-level interface, non-inverted, 8 data bits, no parity, 1 stop bit, baud rate matched to host.
4	SIN	I	Serial input ***from*** host. 3.3 V to 5 V TTL-level interface, non-inverted, 8 data bits, no parity, 1 stop bit, baud rate matched to host.

Type: I = Input, O = Output, P = Power, G = Ground

Use the following example circuit for connecting the Parallax Laser Range Finder Module:



Usage

The LRF Module is controlled by the host via a serial communications interface. To use, simply align the LRF Module towards the target object and send the desired command.

The serial interface is configured for 8 data bits, no parity, 1 stop bit (8N1). Automatic baud rate detection occurs on initial power-up of the LRF Module. The Module waits for a "U" character to be sent by the host and will set its baud rate to match that of the host. Supported baud rates include 300, 600, 1200, 2400, 4800, 9600, 19200, 38400, 57600, and 115200.

When the LRF is ready to receive commands, it will send a ":" to the host. The LRF waits in an idle state until it receives a valid command, at which time it performs the command and returns command-specific data (if any). The LRF will return a "?" upon receiving an invalid command.

The camera system used in the LRF Module has automatic white balance, automatic exposure, and automatic gain control enabled by default, and will automatically adjust its image to account for sudden changes in lighting conditions. However, the LRF works best in a controlled environment, such as indoors with minimal changes in brightness across the frame. The LRF is also less reliable when the laser is shining onto a bright object (for example, a white piece of paper), since the background subtraction performed during image processing could potentially “subtract” the bright laser from the already bright frame.

Status Indicator

A visual indication of the LRF Module’s operating state is given with the on-board LED (Light-Emitting Diode). The LED is located on the back side of the LRF near the center of the board. The LED denotes four states of the LRF:

1. **Green: Idle state**. Waiting for a command to be sent by the host.
2. **Red: Active state**. For example, performing a range calculation or capturing an image with the camera.
3. **Orange (Solid)**: Baud rate detection state. The LRF is waiting for a “U” character to be sent by the host in order to automatically set the communications baud rate. Occurs on LRF power-up only.
4. **Orange (Blinking)**: Error state. The LRF has malfunctioned. A message identifying the failed operation will be transmitted on the SOUT (Serial Out) pin. See Error Modes, page 10, for details.

If the LED is OFF, the LRF may not be receiving power.

Command Set

All commands are single-byte, ASCII printable values and are not case-sensitive (upper case and lower case will both work). No carriage return (CR) or linefeed (LF) is required after the command byte is sent. Depending on the command, data may be returned by the LRF.

The command descriptions in this section are for LRF firmware version 2.0. For command descriptions of earlier firmware versions, refer to product manual version 1.1. Examples are shown for direct connection to a microcontroller (BASIC Stamp 2) and/or to a host PC via a terminal program.

Basic Commands	
R	Single range measurement (returns a 4-digit ASCII value in millimeters)
B	Single range measurement (returns a 2-byte binary value in millimeters)
L	Repeated range measurement (any subsequent byte will stop the loop)
E	Adjust camera for current lighting conditions
S	Reset camera to initial settings
T	Toggle laser on/off
V	Display version information
H	Display available commands

Advanced Commands	
O	Display coordinate, mass, and centroid information for all detected blobs
X	Calibrate camera system for range finding
A	Adjust blob detection parameters
G	Capture & send single frame (160x128, 8 bits/pixel grayscale)
C	Capture & send single frame (320x16, 8 bits/pixel grayscale) w/ laser enabled
P	Capture & send processed frame (320x16, 8 bits/pixel grayscale) w/ background subtraction

Command Details

R: Single range measurement (ASCII)

Takes a single range finding measurement and returns the distance to the target object as a printable ASCII string ("D = ") with a *4-digit decimal* value in millimeters. A range measurement takes ~200 milliseconds to complete.

The LRF Module is most accurate within its optimal measurement range of 6–48 inches (15–122 cm). In ideal conditions, a distance measurement of up to ~8 feet (2.54 meters) may be possible. While the accuracy will be hindered at distances outside of the optimal range, the LRF could still be used for gross distance measurements or simple object detection. See Range and Accuracy, page 10, for details.

Terminal Example:

```
:R
D = 0288 mm
:
```

BS2 Example:

```
SEROUT LRF_TX, LrfBaud, ["R"]  ' Send command

' Wait for distance measurement and store it as a decimal value
SERIN  LRF_RX, LrfBaud, 3000, No_Response, [WAIT("D = "), DEC4 range]
```

B: Single range measurement (binary)

Takes a single range finding measurement and returns the distance to the target object as a *2-byte binary* value in millimeters. Data is sent MSB first. A range measurement takes ~200 milliseconds to complete.

The LRF Module is most accurate within its optimal measurement range of 6–48 inches (15–122 cm). In ideal conditions, a distance measurement of up to ~8 feet (2.54 meters) may be possible. While the accuracy will be hindered at distances outside of the optimal range, the LRF could still be used for gross distance measurements or simple object detection. See Range and Accuracy, page 10, for details.

Terminal Example:

```
:B
<binary data>
:
```

BS2 Example:

```
SEROUT LRF_TX, LrfBaud, ["B"]  ' Send command
SERIN  LRF_RX, LrfBaud, 3000, No_Response, [range.HIGHBYTE, range.LOWBYTE]
```

L: Repeated range measurement

Continuously calls the Single range measurement (ASCII) command ("R"). Once the loop has started, any subsequent byte sent to the LRF Module will stop the command. Each range measurement takes ~200 milliseconds to complete.

Terminal Example:

```
:L
D = 0288 mm
D = 0289 mm
D = 0289 mm
D = 0289 mm
<any key pressed>
:
```

E: Adjust camera for current lighting conditions

Calibrates the LRF Module's camera for the current lighting conditions. This may aid the camera in successfully detecting the laser spot within the frame, which increases accuracy of the range finding functionality.

The command first ensures that automatic white balance (AWB), automatic exposure control (AEC), and automatic gain control (AGC) are enabled. Then, after a 10 second delay for the camera image to settle, AWB, AEC, and AGC are disabled. The EV/exposure level is also reduced to a minimum value. This will cause the entire camera frame, including any previously bright areas, to appear dark. A bright laser spot may now be more easily identifiable within the frame.

The camera's settings can be reset to their default with the "S" command.

Terminal Example:

```
:E
<short delay>
:
```

BS2 Example:

```
SEROUT LRF_TX, LrfBaud, ["E"]
SERIN  LRF_RX, LrfBaud, [WAIT(":")]
```

S: Reset camera to initial settings

Resets and initializes the LRF Module's camera to its default, power-up configuration, including enabling automatic white balance (AWB), automatic exposure control (AEC), and automatic gain control (AGC). It may take up to 10 seconds for the camera image to settle after the command is sent.

This command is particularly helpful when the "E" command has been used to adjust the camera for current lighting conditions and the user wishes to reset the camera settings without power cycling the LRF Module.

Terminal Example:

```
:S
:
```

BS2 Example:

```
SEROUT LRF_TX, LrfBaud, ["S"]
SERIN  LRF_RX, LrfBaud, [WAIT(":")]
```

T: Toggle laser on/off

Allows for manual control of the laser diode. The command will toggle the laser diode on and off. Commands that make use of the laser diode ("R", "B", "L", "O", "X", "C", and "P") will supersede the state set using this command.

Terminal Example:

```
:T
<laser diode on>
:T
<laser diode off>
:
```

BS2 Example:

```
SEROUT LRF_TX, LrfBaud, ["T"]  ' Turn laser diode on
SERIN  LRF_RX, LrfBaud, [WAIT(":")]
SEROUT LRF_TX, LrfBaud, ["T"]  ' Turn laser diode off
SERIN  LRF_RX, LrfBaud, [WAIT(":")]
```

V: Display version information

Lists version and calibration information for the LRF Module. This data is useful for troubleshooting and debugging.

- FW: Firmware revision (major.minor)
- MFG and PID: Manufacturer ID and Product ID of the LRF's on-board camera
- SLOPE, INTERCEPT, PFC_MIN: Device-specific values calculated during the calibration process ("X") and used for range finding (if the LRF Module is uncalibrated, the values will all be 0xFFFFFFFF)
- LOWER_BOUND, UPPER_BOUND, BLOB_MASS_THRESHOLD: Parameters used for blob detection during the range finding process. The values default to those shown in the example output below, but can be changed using the "A" command.

Terminal Example:

```
:V
Parallax Laser Range Finder
Designed by Grand Idea Studio [www.grandideastudio.com]
Manufactured and distributed by Parallax [support@parallax.com]

FW = 2.0
MFG = 7FA2
PID = 7691
SLOPE = +0.001418615 (3AB9F0CE)
INT = -0.009308979 (BC1884B0)
PFC_MIN = 28
LOWER_BOUND = 50
UPPER_BOUND = 255
BLOB_MASS_THRESHOLD = 16
:
```

H: Display available commands

Lists all available commands that the LRF Module supports.

Terminal Example:

```
:H
Basic Commands:
R   Single range measurement
B   Single range measurement (binary response, 2 bytes)
L   Repeated range measurement (any subsequent byte will stop the loop)
<more commands listed, but not shown in this manual>
:
```

O: Display coordinate, mass, and centroid information for all detected blobs

Displays coordinate, mass, and centroid (center of mass) information for up to 6 detected blobs within the camera's field-of-view. This information can be used for custom image processing or object detection outside of the standard LRF Module functionality. The blob detection begins on the left side of the frame and "scans" to the right. See Image Processing and Blob Detection, page 20, for details.

- L: X coordinate of the beginning (left side) of the detected blob
- R: X coordinate of the end (right side) of the detected blob
- M: Mass of blob (sum of all valid pixels within the blob)
- C: Centroid (center of mass) of blob
- <: Marker to indicate if the blob is less than the BLOB_MASS_THRESHOLD
- *: Marker to indicate the blob with the largest mass (primary blob)

In many cases, if a single blob is detected within the frame, it is likely the laser spot. In other cases, there may be reflections of the laser light or other spots that are not related to the laser. Generally, the blob with the largest mass within the frame can be considered the actual laser spot.

Terminal Example:

```
:O
0: L = 81 R = 88 M = 14 C = 84 <
1: L = 137 R = 232 M = 917 C = 181 *
2: L = 235 R = 254 M = 170 C = 244
:
```

X: Calibrate camera system for range finding

To account for manufacturing and assembly variances, particularly related to the camera and laser diode alignments, each LRF Module must be calibrated. This occurs during production, but the LRF can be re-calibrated by the user at a later date if desired. If a new major version of firmware is loaded (for example, upgrading from firmware version 1.0 to 2.0), the LRF will need to be re-calibrated.

The calibration routine requires the user to place the LRF Module at 6 fixed distances (from 20 cm to 70 cm at 10 cm intervals), measured from the front face of the LRF circuit board. The LRF takes measurements at each distance and calculates the SLOPE, INTERCEPT, and PFC_MIN values. The values are then stored in an unused portion of the non-volatile boot Serial EEPROM. They will remain intact during a power cycle.

The SLOPE and INTERCEPT are used to convert the pixel offset to an angle using a best-fit slope-intercept linear equation. The PFC_MIN value is used to set the maximum allowable distance of the LRF Module, which is represented by a minimum pixels from center value. See Optical Triangulation, page 17, for details.

The LOWER_BOUND, UPPER_BOUND, and BLOB_MASS_THRESHOLD parameters, used for blob detection during range finding, are reset to their default values during this process (50, 255, and 16, respectively).

A video demonstrating the calibration process can be found on YouTube:
www.youtube.com/watch?v=1gk_tRbJO84

Terminal Example:

```
:X
Are you sure you want to calibrate (Y/N)?Y
Set LRF to D = 20 cm and press spacebar (any other key to abort)
pfc: 289 angle: 0.3718561
pfc: 289 angle: 0.3718561
pfc: 290 angle: 0.3718561
pfc: 289 angle: 0.3718561

< more steps listed, but not shown in this manual >

Set LRF to D = 70 cm and press spacebar (any other key to abort)
pfc: 105 angle: 0.1109708
pfc: 105 angle: 0.1109708
pfc: 105 angle: 0.1109708
pfc: 105 angle: 0.1109708

SLOPE = +0.001420366 (3ABA2B96)
INT = -0.03679396 (BD16B544)
PFC_MIN = 48
LOWER_BOUND = 50
UPPER_BOUND = 255
BLOB_MASS_THRESHOLD = 16

Write new values (Y/N)?Y
:
```

A: Adjust blob detection parameters

Receive new blob detection parameters from the user and store them in memory. The current value is displayed within the square brackets ([]). Each parameter can have a value from 0 to 255 and must be followed by a carriage return (CR). If the entered value is out of range, an error message will be displayed and the command will abort. When all parameters have been properly entered, they are stored in an unused portion of the non-volatile boot Serial EEPROM. They will remain intact during a power cycle.

LOWER_BOUND is the minimum brightness value and UPPER_BOUND is the maximum brightness value used during the thresholding phase of blob detection. If a pixel within the processed frame is greater than or equal to LOWER_BOUND (default of 50) and less than or equal to UPPER_BOUND (default of 255), it is set to ‘1’ (white) and included in the column sum. Otherwise, it is set to ‘0’ (black).

BLOB_MASS_THRESHOLD is the minimum blob mass (the number of valid ‘1’ pixels within the total blob) required for the blob to be considered as the primary blob. If the blob mass is greater than or equal to BLOB_MASS_THRESHOLD (default 16), it is included. This parameter reduces the chance of using an unlikely blob (such as one caused by optical noise or reflection) for range finding calculations.

See Image Processing and Blob Detection, page 20, for details.

Terminal Example:

```
:A
Enter new LOWER_BOUND [50]: 40
Enter new UPPER_BOUND [255]: 200
Enter new BLOB_MASS_THRESHOLD [16]: 30
:
```

G: Capture & send single frame (160x128, 8 bits/pixel grayscale)

Capture a 160x128 resolution grayscale image with the LRF Module's camera and return the data in a binary format.

The data is sent MSB first, one byte per pixel, starting at the upper-left pixel location (0,0), moving left to right, top to bottom across the frame, and ending at the lower-right pixel location (160,128). Each byte corresponds to the brightness value of a single pixel where 0x00 is black and 0xFF is white.

A total of 20,480 bytes of binary data is sent. An ASCII footer ("END") is attached to the end of the binary data stream to assist in identifying the end of the frame.

This command can be used from within the LRF Image Viewer tool to easily view the image.

Terminal Example:

```
:G
<binary data>END
:
```

C: Capture & send single frame (320x16, 8 bits/pixel grayscale) w/ laser enabled

Capture a 320x16 resolution grayscale image with the LRF Module's camera and return the data in a binary format. The laser diode is enabled during the frame grab for testing and alignment purposes.

The data is sent MSB first, one byte per pixel, starting at the upper-left pixel location (0,0), moving left to right, top to bottom across the frame, and ending at the lower-right pixel location (320,16). Each byte corresponds to the brightness value of a single pixel where 0x00 is black and 0xFF is white.

A total of 5,120 bytes of binary data is sent. An ASCII footer ("END") is attached to the end of the binary data stream to assist in identifying the end of frame.

This command can be used from within the LRF Image Viewer tool to easily view the image.

Terminal Example:

```
:C
<binary data>END
:
```

P: Capture & send processed frame (320x16, 8 bits/pixel grayscale)

Capture a 320x16 resolution processed image with the LRF Module's camera and return the data in a binary format. This mode is specific for range finding functionality and consists of a "background subtracted" image where one frame is taken with the laser diode off, one frame taken with the laser diode on, and the data of the two frames subtracted. This helps to isolate the laser spot within the frame. See Image Processing and Blob Detection, page 20, for more details.

The data is sent MSB first, one byte per pixel, starting at the upper-left pixel location (0,0), moving left to right, top to bottom across the frame, and ending at the lower-right pixel location (320,16). Each byte corresponds to the brightness value of a single pixel where 0x00 is black and 0xFF is white.

A total of 5,120 bytes of binary data is sent. An ASCII footer ("END") is attached to the end of the binary data stream to assist in identifying the end of frame.

This command can be used from within the LRF Image Viewer tool to easily view the image.

Terminal Example:

```
:P
<binary data>END
:
```

Range and Accuracy

The LRF Module is most accurate within its optimal measurement range of 6–48 inches (15–122 cm). Within this range, error can span from zero (no difference between actual distance and the distance calculated by the LRF) to 5%. On average, the error is approximately 3%.

Within the optimal measurement range, the horizontal position of the laser spot within the camera's frame (which is used to determine distance to the target object) changes noticeably. At longer distances, although the camera can still "see" the laser spot, the horizontal position does not change as much, causing a significant reduction in accuracy. Accuracy also varies with lighting conditions and material of the target object, which affect the LRF Module's capability to determine the laser spot within the camera's frame.

The LRF Module intentionally limits the maximum detectable distance to 100 inches (254 cm). At distances less than 6 inches, the laser spot is out of the camera's field-of-view, so no range calculation can occur. See Optical Triangulation, page 17, for more details.

The following chart shows example measurements taken with a LRF Module. The Calculated Distance, Difference (Δ), and % Error will vary slightly per unit.

Actual Distance to Target (cm)	Calculated Distance (cm)	Difference (Δ)	% Error
20	19.9	0.1	-0.50
30	29.7	0.3	-1.00
40	40.1	-0.1	0.25
50	50.3	-0.3	0.60
60	60.2	-0.2	0.33
70	70.8	-0.8	1.14

Average % Error

0.64

Actual Distance to Target (in)	Calculated Distance (in)	Difference (Δ)	% Error
10	9.9	0.1	-1.00
20	20.1	-0.1	0.50
30	30.7	-0.7	2.33
40	40.3	-0.3	0.75
50	48.8	1.2	-2.40
75	70.3	4.7	-6.27

Average % Error

2.21

Error Modes

In the event that the LRF enters the error state (signified by a blinking orange LED status indicator), an ASCII message identifying the failed operation will be transmitted on the SOUT (Serial Out) pin.

Messages include:

- **ERR: cam.start**. Error initializing the camera on LRF power-up. This may be caused by a communication error between the Propeller and camera.
- **ERR: cam.init**. Error performing the "S" command (Reset camera to initial settings). This may be caused by a communication error between the Propeller and camera.

- **ERR: cam.calibrate**. Error performing the “E” command (Adjust camera for current lighting conditions). This may be caused by a communication error between the Propeller and camera.
- **ERR: cam.setRes**. Error setting the camera’s resolution. This may be caused by a communication error between the Propeller and camera.
- **ERR: cam.getID**. Error retrieving the camera’s manufacturer and product IDs. This may be caused by a communication error between the Propeller and camera.
- **ERR: eeprom.ReadLong**. Error reading calibration data from the external Serial EEPROM. This may be caused by a communication error between the Propeller and EEPROM or an incorrect type of EEPROM device.
- **ERR: eeprom.WriteLong**. Error writing calibration data to the external Serial EEPROM. This may be caused by a communication error between the Propeller and EEPROM or an incorrect type of EEPROM device.

If the LRF is in an error state, but no error message is transmitted, then there is likely a failure with starting either the serial communication or auto baud detection cog.

For further assistance, please contact Parallax technical support.

Electrical Characteristics

At V_{CC} = +5.0 V and T_A = 25 ºC unless otherwise noted.

Parameter	Symbol	Specification			Unit
		Min.	Typical	Max.	
Supply Voltage	V_{CC}	4.5	5.0	5.5	V
Supply Current, Idle	I_{IDLE}	---	82	---	mA
Supply Current, Active	I_{CC}	---	126	150	mA

Absolute Maximum Ratings

Condition	Value
Operating Temperature	0 ºC to +50 ºC (+32 ºF to +122 ºF)
Storage Temperature	-40 ºC to +125 ºC (-40 ºF to +257 ºF)
Supply Voltage (V_{CC})	+4.5 V to +5.5 V
Ground Voltage (V_{SS})	0 V
Voltage on any pin with respect to V_{SS}	-0.3 V to +7.0 V

NOTICE: Stresses above those listed under “Absolute Maximum Ratings” may cause permanent damage to the device. This is a stress rating only and functional operation of the device at those or any other conditions above those indicated in the operation listings of this specification is not implied. Exposure to maximum rating conditions for extended periods may affect device reliability.

LRF Image Viewer

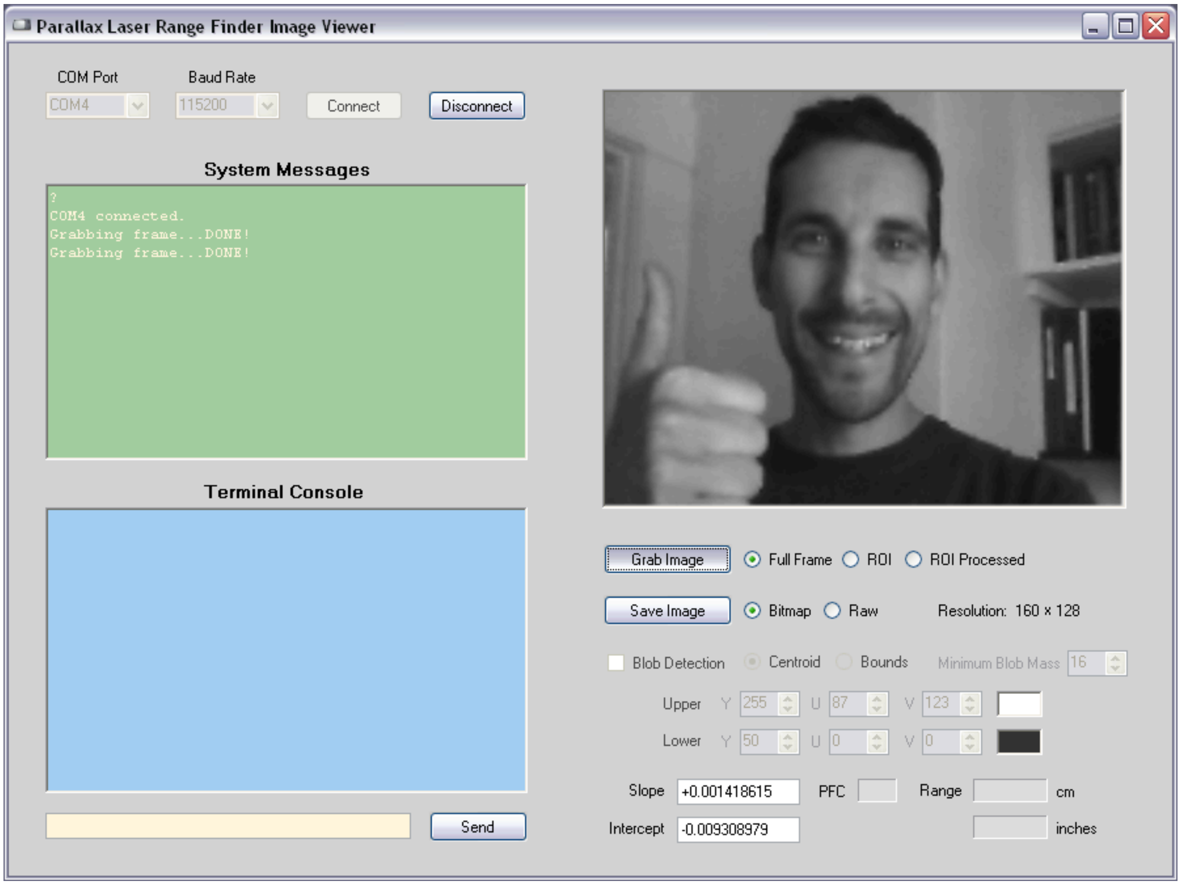
The LRF Image Viewer is an easy-to-use, PC-based graphical interface that allows direct and simple control of the LRF Module:

- Send commands to the LRF
- Read system/debug messages from the LRF
- Capture/display/save images from the LRF's camera
- Enable PC-side image processing functionality (blob detection and identification, range/distance calculations)

The LRF Image Viewer supports all versions of LRF Module firmware. Features vary slightly depending on firmware version. The user interface will be configured automatically after successful connection to the LRF Module (using the Connect button). The descriptions in this section are for LRF firmware version 2.0. For descriptions of earlier firmware versions, refer to the LRF Module product manual version 1.1.

The LRF Image Viewer application was designed in Microsoft Visual Basic .NET. It requires Microsoft's .NET Framework Version 2.0 Redistributable Package to be installed on the host PC: http://download.cnet.com/Microsoft-NET-Framework-Redistributable-Package-x86/3000-10250_4-10726028.html

The LRF Module connects to the host PC via its TTL-level serial interface through a USB-to-Serial adapter (Parallax #28024 or compatible). A demonstration of an early release of the LRF Image Viewer can be found on YouTube: www.youtube.com/watch?v=iHvMl2scUdA



COM Port: COM4
Baud Rate: 115200

```
?
COM4 connected.
Grabbing frame...DONE!
Grabbing frame...DONE!
```

● Full Frame ○ ROI ○ ROI Processed

● Bitmap ○ Raw   Resolution: 160 x 128

□ Blob Detection ● Centroid ○ Bounds   Minimum Blob Mass 16

Upper Y 255 U 87 V 123

Lower Y 50 U 0 V 0

Slope +0.001418615

Intercept -0.009308979

LRF Image Viewer Interface

The LRF Image Viewer has a variety of windows, controls, and features:

COM Port menu: Provides a selection of COM ports available on the host PC (includes any virtual serial ports provided by common USB-to-Serial interfaces)

Baud Rate menu: Provides a list of supported baud rates (9600, 19200, 38400, 57600, and 115200).

Connect/Disconnect buttons: Opens/closes a serial connection on the specified COM port at the selected baud rate. After opening a serial connection with the Connect button, the LRF Image Viewer will send the required “U” character to allow the LRF Module to automatically detect the host PC’s baud rate.

System Messages window: Displays operational or debug messages sent by the LRF Image Viewer software.

Terminal Console window: Displays the data sent to and received from the LRF Module via its serial interface.

Text Entry box: This yellow text box beneath the Terminal Console allows the user to type commands and send them directly to the LRF Module. The text is only transmitted when the Send button (or Enter key) is pressed. Any data returned by the LRF will be displayed in the Terminal Console.

Image window: Displays an image captured by the LRF Module.

Grab Image button: Captures an image with the LRF Module’s camera and displays it in the Image Window. The adjacent radio buttons are used to select one of three image types:

- Full Frame: 160x128 resolution grayscale image, achieved by sending a “G” command to the LRF.
- ROI: 320x16 resolution grayscale image, achieved by sending a “C” command to the LRF. The laser diode is enabled during the frame grab for testing and alignment purposes.
- ROI Processed: 320x16 resolution “processed” grayscale image, achieved by sending a “P” command to the LRF. The image is created by capturing one frame with the laser diode off, another frame with the laser diode on, and then subtracting the data of the two frames. This helps to isolate the laser spot within the frame, which is useful for range finding functionality.

Save Image button: Saves the image currently displayed in the Image Window. The adjacent radio buttons are used to select a file type of standard bitmap (.BMP) or raw binary (8 bits/pixel grayscale, each byte corresponding to the brightness value of a single pixel where 0x00 is black and 0xFF is white).

Blob Detection and Range Finding functionality: Enables the LRF Image Viewer to use its internal image processing and blob detection routines (instead of the functionality on-board the LRF Module) to identify pixels within a captured frame and to calculate range/distance.

Upon successful connection of the LRF Module to the LRF Image Viewer (using the Connect button), the control boxes are populated with values retrieved from the LRF Module.

The Blob Detection checkbox is only available when the ROI Processed radio button is selected (located next to the Grab Image button). When the checkbox is selected, the adjacent controls become available.

The Upper and Lower controls are used to set the maximum and minimum brightness values, respectively, that a pixel must fall between in order for it to be displayed and included for range finding purposes. The corresponding shade of grey is displayed next to the controls. These controls represent the UPPER_BOUND and LOWER_BOUND values on the LRF Module.

The Minimum Blob Mass control is the minimum blob mass required for the blob to be considered as the primary blob. If the blob mass is greater than or equal to the value, it is included. This parameter reduces the chance of using an unlikely blob (such as one caused by optical noise or reflection) for range finding calculations. This control represents the BLOB_MASS_THRESHOLD value on the LRF Module.

The above 3 controls can be manually adjusted to help fine-tune the LRF Module for ideal operation within a specific environment. Once the desired values are obtained, they can be stored in the LRF Module using the “A” command.

The Centroid and Bounds radio buttons are used to choose how to mark the primary blob if one is detected. The Centroid selection draws a red vertical line through the centroid (center of mass) of the blob. The Bounds selection draws red vertical lines at the beginning and end locations (left and right) of the blob.

The Slope and Intercept text boxes show the respective values used during the range finding process. These values vary per module and calculated during calibration (“X”).

The Pixels from Center text box displays the number of pixels the primary blob is away from the center point of the frame. This value is used for range finding calculations.

The Range text boxes show the calculated distance to the target object in centimeters (top) and inches (bottom).

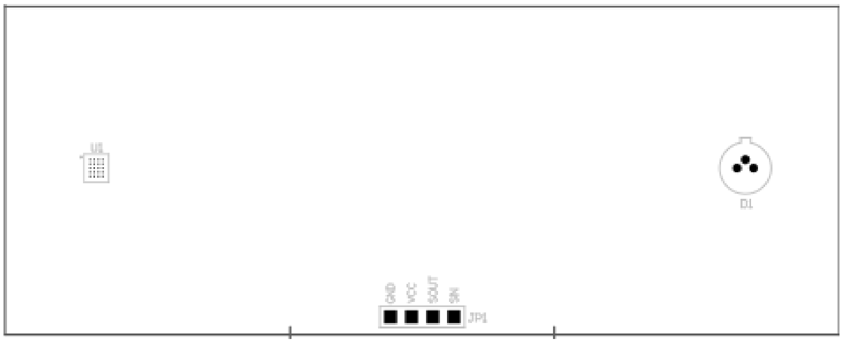
Hardware Design

The LRF Module’s major hardware components include:

- Parallax Propeller P8X32A-Q44
- OmniVision OVM7690 640x480 CMOS CameraCube
- Arima APCD-635-02-C3-A Laser Diode

Assembly Drawing

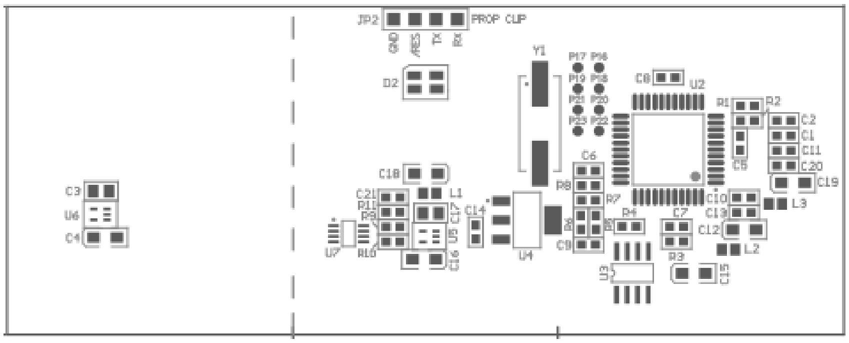
All components are mounted on the back side of the board with the exception of the camera and laser diode. The center points of the camera and laser diode are 78 mm apart.



On the back side of the LRF Module, the Propeller (U2), its supporting electronics, and the camera interface circuitry are located on the right and the laser diode control circuitry is on the left. A dotted line (not printed on the actual LRF Module) indicates the recommended cutting point if the user wishes to separate the laser diode control circuitry from the rest of the LRF for custom projects.

A Prop Plug (Parallax #32201) can attach to the four pads (JP2) on the back of the LRF in order to reprogram the Propeller’s firmware using the Parallax Propeller Tool software. Calibration and parametric data will remain intact provided the same major version of firmware is loaded. Otherwise, the LRF will need to be re-calibrated using the “X” command (for example, if upgrading from firmware version 1.0 to 2.0).

Eight unused GPIO pins (P16-P23) are available via surface mount pads near the Propeller. The pins are spaced to support a dual-row, 0.1” male header.



Theory of Operation

This section describes advanced details of the LRF Module operation.

Program Structure

As of LRF Module firmware version 2.0, the source tree consists of 5 custom objects and 7 objects either included with the Parallax Propeller development environment or written by others and posted to the Parallax Object Exchange (http://obex.parallax.com). Objects with a _Lite prefix have been modified from their original to remove unused code and/or to meet needs specific to the LRF Module.

```
LRF_OVM7690.spin
│
├──LRF_con.spin
│
├──OVM7690_obj.spin
│      │
│      ├──LRF_con.spin
│      │
│      ├──OVM7690_fg.spin
│      │      │
│      │      └──LRF_con.spin
│      │
│      ├──OVM7690_fg_roi.spin
│      │      │
│      │      └──LRF_con.spin
│      │
│      ├──pasm_i2c_driver_Lite.spin
│      │
│      └──Synth.spin
│
├──JDCogSerial_Lite.spin
│
├──F32_Lite.spin
│
├──FloatString_Lite.spin
│      │
│      └──FloatMath_Lite.spin
│
└──Basic_I2C_Driver_Lite.spin
```

LRF_OVM7690.spin is the top object file. This object handles the user interface, command processing, and laser range finding mathematics.

LRF_con.spin provides the global constants used throughout the program, including camera resolution, blob detection, range finding, and calibration settings.

OVM7690_obj.spin provides the low-level communication interface for the OmniVision OVM7690 CMOS CameraCube module.

OVM7690_fg.spin and **OVM7690_fg_roi.spin** are the frame grabber objects for 160x128 and 320x16 grayscale images, respectively. They retrieve data from the OVM7690 and store it in the hub RAM frame buffer. OVM7690_fg_roi.spin also provides a subset of blob detection functionality. The objects are written in Propeller Assembly (PASM) due to their complex timing requirements.

pasm_i2c_driver_Lite.spin provides the I2C protocol interface for communication with the OVM7690. Written by Dave Hein.

Synth.spin is a frequency synthesizer used to generate the clock signal required by the OVM7690. Included with the Parallax Propeller Tool.

JDCogSerial_Lite.spin provides full-duplex serial communication. Written by Carl Jacobs.

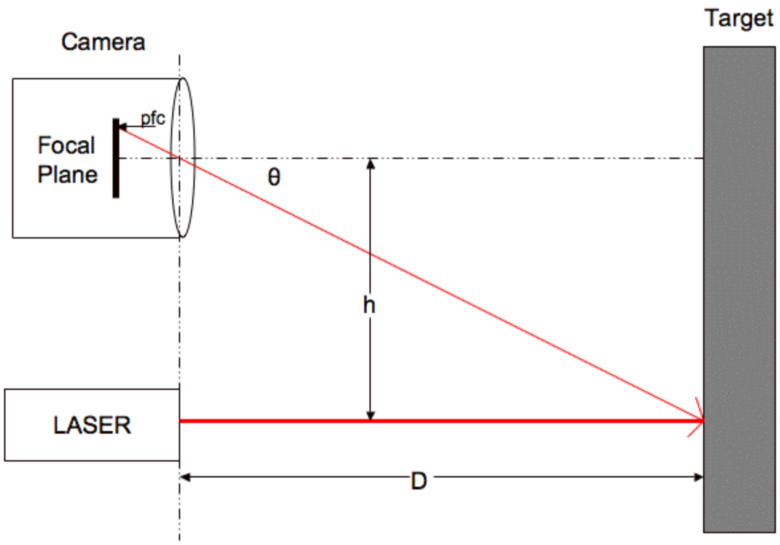
F32_Lite.spin provides IEEE 754-compliant 32-bit floating point math routines used for range finding and calibration. Written by Jonathan "lonesock" Dummer.

FloatString_Lite.spin and **FloatMath_Lite.spin** provide IEEE 754-compliant 32-bit floating point-to-ASCII string conversion routines. Included with the Parallax Propeller Tool.

Basic_I2C_Driver_Lite.spin provides the I2C protocol interface for boot EEPROM communication. The LRF Module has a 64KB boot EEPROM. Only the first 32KB is used by the Propeller for program storage, so the remaining 32KB is available for data storage. Each LRF Module's calibration values and blob detection parameters are stored in the data area. Written by Michael Green.

Optical Triangulation

The LRF Module uses optical triangulation for range finding, where the distance to the target object is calculated with simple trigonometry between the center points of laser light, camera, and object. The design of the LRF Module is based, in theory, on the implementation of Todd Danko's Webcam Based DIY Laser Rangefinder (https://sites.google.com/site/todddanko/home/webcam_laser_ranger).



Referring to the figure above, a laser diode module shines a laser spot onto the target object. The value h is a fixed, known distance between the center points of the laser diode and the camera (78 mm for the LRF Module). When the distance to the target object D changes, so do both the angle θ and the value pfc (pixels from center), which is the number of pixels the centroid of the primary blob (laser spot) is away from the camera's center point.

As the object gets closer, the value of pfc (and angle θ) increases. As the object gets farther away, pfc (and angle θ) approaches zero. If the angle θ is known, then trigonometry can be used to calculate the distance value D:

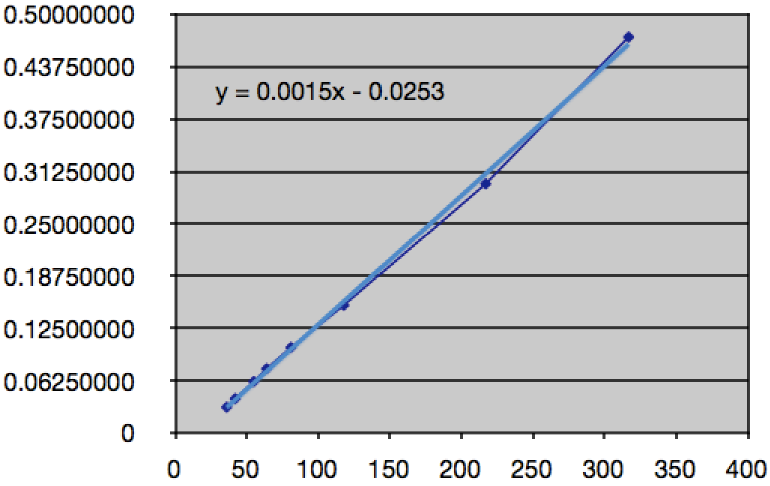
$$\tan \theta = h / D$$

Solving for D:

$$D = h / \tan \theta$$

Since the LRF Module's blob detection routine returns a pfc value, an intermediate step is required to correlate that value with an actual angle θ. The relationship between pfc and angle can be described with a slope-intercept linear equation (www.math.com/school/subject2/lessons/S2U4L2GL.html).

The following chart shows measurements taken with a LRF Module. pfc is on the X-axis and angle is on the Y-axis. The dark blue diamonds show the actual measurements and the resulting best-fit linear equation is printed on the chart and denoted with a light blue line:



Once the laser is shined onto the target object and the pfc value of the laser spot is received, an angle θ can be calculated using the slope-intercept equation and passed to the trigonometric function to determine the actual distance the range finder is from the target object.

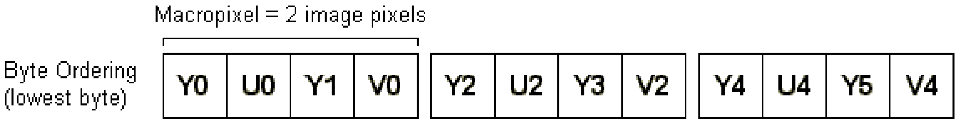
To account for manufacturing and assembly variances, particularly related to the camera and laser diode alignments, each LRF Module must be calibrated using the "X" command. This will determine the ideal slope and intercept values for that particular module.

Camera Interface

The OmniVision OVM7690 640x480 CMOS CameraCube provides a digital interface:

- **DVP[7:0] (Digital video port)**: 8-bit wide output bus corresponding to pixel information sent in the selected output format from the OVM7690 (RAW RGB, RGB565, CCIR656, or YUV422/YCbCr422).

  The LRF Module is configured for YUV422 output (https://en.wikipedia.org/wiki/YUV and https://en.wikipedia.org/wiki/YCbCr). Y is the luma component - brightness in grayscale - and U and V are chroma components - color differences of blue and red, respectively. The particular format of YUV422 used by the OVM7690 is known as YUY2 (www.fourcc.org/yuv.php), in which each 16-bit pixel is given an 8-bit Y component and alternating 8-bit U or 8-bit V component:

  Y0U0 corresponds to a single pixel starting from the left, Y1V0 is the 2nd pixel, etc. Every pixel has Y data, and U and V are every other pixel. The LRF Module only uses the grayscale portion (Y) of the output. The chroma components (U/V) are ignored.

- **VSYNC (Vertical sync)**: Indicates the beginning of a new frame by pulsing high.
- **HREF (Horizontal reference)**: Indicates the start of the next row of pixels by pulsing high. By keeping count of the number of HREF pulses received since the last VSYNC, we can determine which horizontal line of the video frame we are currently on.
- **PCLK (Pixel clock)**: Asserted when valid pixel data is available on the DVP bus. For a 640 pixel line in YUV422 format (16 bits/pixel), 10,240 pixel clock cycles will occur after each HREF pulse.

There are nearly one hundred 8-bit registers within the OVM7690 device that require configuration, including, but not limited to, general settings, output format selection, resolution, frames per second, automatic white balance, and gain control. Due to confidentiality concerns, OmniVision does not allow explicit references or detailed explanations of camera configuration registers. Explanations of group settings are allowed and provided within the LRF Module source code to give the user an overview of camera operation. To obtain full OVM7690 product specifications, a non-disclosure agreement (NDA) must be executed with OmniVision Technologies, Inc. (www.ovt.com).

Frame Grabber

The frame grabber cogs (OVM7690_fg.spin and OVM7690_fg_roi.spin) only execute when started by a calling object. They receive 160x128 and 320x16 grayscale images, respectively, and store them in the frame buffer. OVM7690_fg_roi.spin also handles the background subtraction, pixel thresholding, and column summing phases of blob detection (needed for the range finding process). The objects are written in Propeller Assembly (PASM) due to their complex timing requirements.

Grabbing a frame consists of waiting for VSYNC to go high, which signals the start of a new frame, and then waiting for HREF to go high, which signals the start of a new line. Then, pixel data (Y/luma only) is captured from DVP[7:0] every time PCLK goes high and is stored in the frame buffer. After the complete frame is stored in the buffer, the cog sets a flag in hub RAM to a non-zero state so the calling object knows that the frame grab is done. The cog then stops itself.

The frame grabber cogs support three modes:

1. **Single Frame, 160x128**: 8 bits/pixel grayscale image (in OVM7690_fg.spin).

2. **Single Frame, 320x16**: 8 bits/pixel grayscale image (in OVM7690_fg_roi.spin). The laser diode is enabled during the frame grab for testing and alignment purposes.

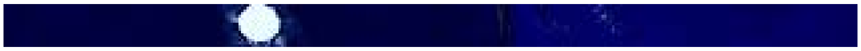
3. **Processed Frame, 320x16**: 8 bits/pixel processed grayscale image (in OVM7690_fg_roi.spin). This mode is specific for range finding functionality and consists of a "background subtracted" image where one frame is taken with the laser diode off, one frame taken with the laser diode on, and the data of the two frames subtracted. This helps to isolate the laser spot within the frame. The frame grabber then handles the pixel thresholding and column summing phases of blob detection. The results of the column summing are stored in an array in hub RAM.

Image Processing and Blob Detection

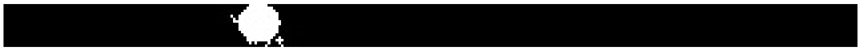
The primary function of the LRF Module is to capture an image with the camera and determine the location of the laser spot (blob) within the frame. Once the blob is detected, its centroid (center of mass) and resulting pfc value (pixels from center) are determined and passed to the routine that calculates the distance from the LRF to the target object.

The LRF Module's image processing and blob detection functions as follows:

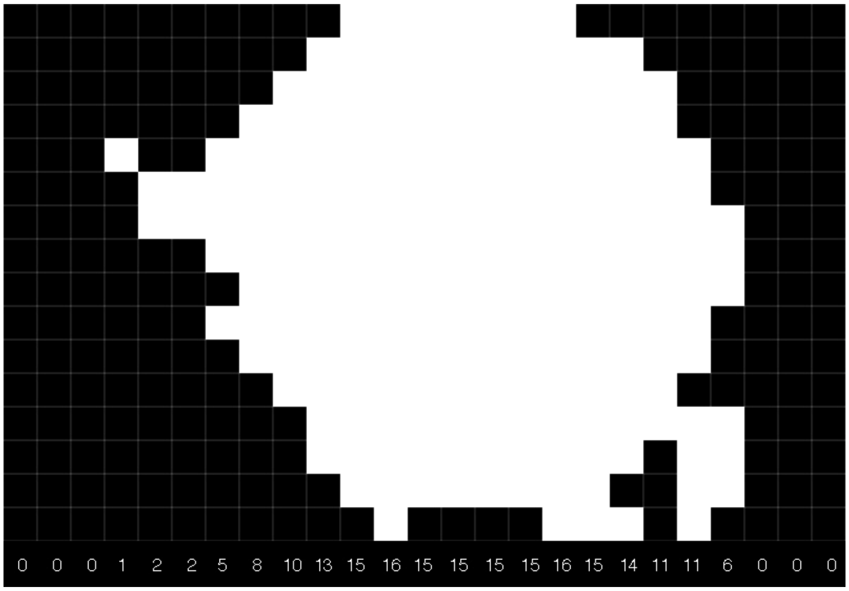
1. **Background Subtraction.** Grab two consecutive frames—one with the laser diode off and one with the laser diode on. Each pixel's Y/luma component from the first frame is subtracted from the same pixel's Y/luma component from the second frame (and absolute valued), leaving only the pixels that have changed in brightness between the two frames. All other background details (anything that has stayed the same between the two frames) disappear. More information on pixel/background subtraction can be found at:
http://homepages.inf.ed.ac.uk/rbf/HIPR2/pixsub.htm



2. **Thresholding.** Look at the grayscale value of each pixel in the processed frame (8 bits, where 0x00 is black and 0xFF is white) and determine if it is within the defined brightness bounds. If a pixel is greater than or equal to LOWER_BOUND (default of 50) and less than or equal to UPPER_BOUND (default of 255), it is set to '1' (white). Otherwise, it is set to '0' (black):



3. **Column Sum**. Count the number of '1' pixels within each vertical column. This results in a one-dimensional array containing the number of "valid" pixels per column. Summing the valid pixels makes it easier to quickly search the frame to locate any blobs. The following image shows the zoomed-in blob with the column's sum printed at the bottom of each column:



4. **Blob Detection.** Traverse the one-dimensional array of column sums to identify a valid blob. If the column sum is above a defined threshold (SUM_THRESHOLD), it will be considered part of the blob. For example, in the image from Step 3, if the threshold is 4, the blob would start at column 7 (which has a sum of 5) and end at column 22 (which has a sum of 6). This is repeated across the entire frame from left to right until all blobs have been detected.

5. **Mass/Centroid Calculation.** Calculate the total mass and centroid for the detected blob(s) in the frame. The *mass* is simply the number of valid '1' pixels within the total blob. The *centroid* of a blob is its center of mass and is calculated by weighting every valid pixel with where it is in the blob and averaging by the total mass:

   For column 1..n of the blob

   sum = 1 * s1 + (2 * s2) + ... + (n * sn)

   Where sn = column sum for column n

   Then, centroid = sum / mass

   Performing the weighted average (as opposed to simply setting the centroid location as the center point of the blob) gives a more accurate center of mass result regardless of blob shape.

   Here's an example of determining the centroid using the blob from Step 3:

   sum = (1 * 5) + (2 * 8) + (3 * 10) + ... + (15 * 11) + (16 * 6) = 1737

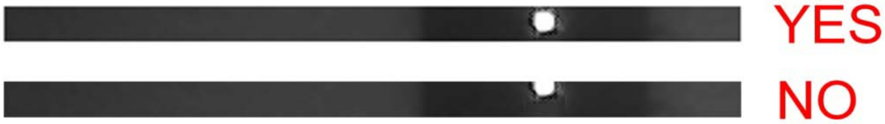
   centroid = sum / mass = 1737 / 200 = ~8.7

   The blob with the largest mass is then chosen as the primary blob (which is assumed to be the actual laser spot) and will be used for the subsequent range finding calculation. If there are multiple blobs with the same mass, the first occurrence remains the primary.

Care and Handling

Alignment of the laser diode and camera are critical to the proper operation of the LRF Module. Both components are aligned during production and reinforced to the printed circuit board with cyanoacrylate adhesive. Care should be taken to protect the LRF Module from sudden shock, excessive vibration, or blunt force.

To verify proper alignment of the LRF Module, use the LRF Image Viewer tool. Place the LRF Module 20 to 30 inches (50 to 70 mm) away from a target object (preferably a grey or other non-white surface). Ensure the ROI radio button is selected and press the Grab Image button. A grayscale image with a laser spot (light gray or white) should be displayed in the image box. The laser spot should be centered vertically within the frame:

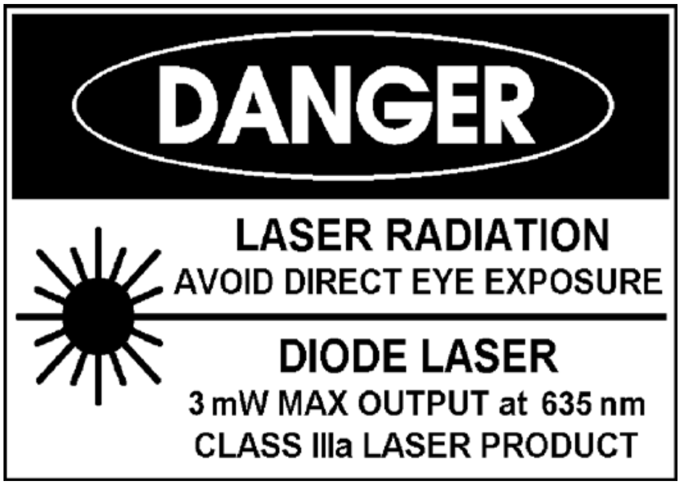


If the laser spot is out of position, the laser diode will need to be manually adjusted and the LRF Module will need to be re-calibrated using the “X” command.

Safety

The LRF Module uses an Arima APCD-635-02-C3-A Laser Diode that contains integrated automatic power control (APC) circuitry and a glass collimating lens. The laser diode is a Class IIIa laser device with a maximum power output of <= (less than or equal to) 3 mW @ 635 nm. The laser diode is enabled for ~100 ms during a single frame capture.

To prevent eye damage, do not stare into the laser diode output on the front of the LRF Module. Many documented cases of eye damage with Class IIIa devices (which include, for example, most run-of-the-mill red laser pointers, laser levels, and laser-based thermometers), were caused by prolonged exposure of the direct laser output: https://en.wikipedia.org/wiki/Laser_safety#Laser_pointers



DANGER

LASER RADIATION
AVOID DIRECT EYE EXPOSURE

DIODE LASER
3 mW MAX OUTPUT at 635 nm
CLASS IIIa LASER PRODUCT

Open Source Files and Example Code

All engineering materials are released as open source under a Creative Commons Attribution 3.0 United States license (http://creativecommons.org/licenses/by/3.0/us/), allowing free distribution and reuse provided that proper attribution is given to the original author. The materials are posted on the Laser Range Finder product page; search for “28044” at www.parallax.com:

- Product Manual (this document)
- Firmware
- Schematic
- Bill-of-Materials
- PCB Layout
- Mechanical Drawing
- Example Code for BASIC Stamp 2, Propeller P8X32A, and Arduino
- LRF Image Viewer

Additional Resources

- Grand Idea Studio’s *Laser Range Finder* web page: www.grandideastudio.com/portfolio/laser-range-finder/
- Demonstration videos: www.youtube.com/playlist?list=PLsyTdiI7kVn-FuHX_4S52HdA8oJjImwHI
- Sam’s Laser FAQ: www.repairfaq.org/sam/lasersam.htm

Revision History

Version 2.0

- Major revisions to reflect the new features and commands of LRF firmware version 2.0
- Removed example code listings
- Modified some command descriptions to include examples of communication with a host microcontroller

Version 1.1

- Added text regarding current sample rate to the Features list and R, B, and L commands
- Updated URLs
- Changed baud rate list for the LRF Image Viewer tool
- Added Arduino example code