# Characterization of Hokuyo Laser Rangefinders in Terms of Material Recognition

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***Abstract- This paper presents the characterization of laser rangefinders (LRF) in terms of material recognition for nondestructive testing (NDT). The laser rangefinders shall be used for structural inspection of structures (indoor & outdoor) which is a tiresome task if done manually. Mounting these lasers on a flight robot will enable the user to inspect the structure by remote control in a much more efficient way. The LRF shall map the distance to the structure being inspected and is also able to find its boundaries e.g. between different materials. The aim is to evaluate and select the best laser for the aforementioned purpose. Here we used Hokuyo URG-04LX laser. This is a 2D LIDAR scanning laser rangefinders. The lasers are evaluated on their scope of application, shape recognition capabilities, amount of mixed pixilation and so on.***

***Keywords- Hokuyo laser, Octocopter and rangefinder***

## I. INTRODUCTION

The Octocopter is a multicopter flight robot. Basically it is a rotorcraft with more than two rotors. Multicopter often use fixed-pitch blades, whose rotor pitch does not vary as the blades rotate; control of vehicle motion is achieved by varying the relative speed of each rotor to change the thrust and torque produced by each.

Figure:1. Octocopter (structural inspection flying robot for NDT)

This Octocopter has 8-propeller system which is radio controlled and widely used as a low-budget option to create aerial photography and videos of sites and buildings.

For NDT purposes, this Octocopter it used at Fraunhofer IZFP to scan infrastructures such as buildings with high resolution digital cameras. Out of these images taken at high speed, full 2D and 3D reconstruction building models are created allowing remote inspections of the infrastructure. As an additional sensor in the future, the lasers will serve as a rangefinder for navigation, also assisting in structural inspection by detecting surface damages e.g. cracks and obstacles.
Laser Rangefinder- Range sensing is an important criterion of any structural inspection system for mobile robots as mentioned above. The LRF must have a wide array of application capable of using both indoors and outdoors. Next it must be able to recognize shapes with good accuracy and have least mixed pixilation. Also the maximum range of the laser being used is of high importance.

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## II. HOKUYO URG-04LX LRF

The Hokuyo URG-04LX is an LRF categorized as amplitude modulated continuous wave (AMCW) sensor. As depicted in Figure 2, the laser emits an infrared beam and a rotating mirror changes the beam's direction. Then the laser hits the surface of an object and is reflected. The direction of reflected light is changed again by a rotating mirror, and captured by the photo diode. The phases of the emitted and received light are compared and the distance between the sensor and the object is calculated. A rotating mirror sweeps the laser beam horizontally over a range of 240°, with an angular resolution of 0.36°. As the mirror rotates at about 600 rpm, the scan rate is about 100 millisecond and 9 Mbps when connected via USB.
The USB connection is thus much preferable and it was used for our tests. The LRF has a quoted range of between 20 and 4,095 mm. The quoted measurement error is ±10 mm for distances of less than 1 m. For greater distances, the error is quoted as ±2%, assuming a target of a patch of white paper of size 70×70 mm. The measured range is discredited to 12-bits. If the sensor detects an error, an error code is sent with the same 12-bit range measurement. For example, the sensor emits error messages if the distance exceeds the limit, or if the received light is too strong or weak.

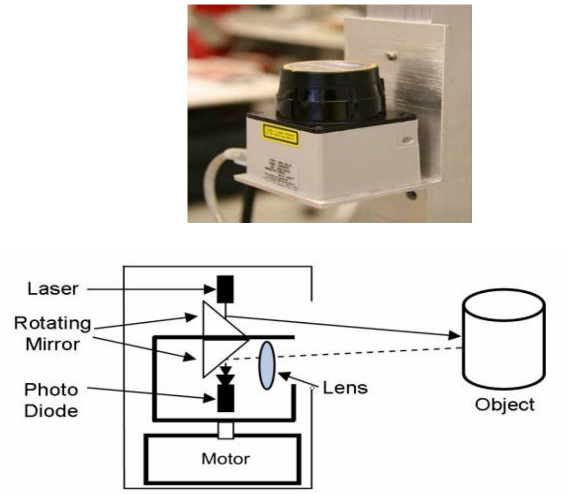


Figure: 2. Operation principle of the Hokuyo LRF

Table: 1. Product and scanning

| S.No. | Product name | Scanning laser rangefinder |
|---|---|---|
| 1. | Model | URG-04-LX |
| 2 | Light source (Laser safety Class 1) | Semiconductor laser diode (λ=785nm),Laser power : less than 0.8Mw |
| 3. | Power voltage | 5VDC ±5% |
| 4. | Detection | 60 mm ~ 4,095mm (Guaranteed accuracy distance) |
| 5. | Accuracy | Distance 20 ~ 1000mm : ±10mm, Distance 1000 ~ 4000mm : ±1% of measurement |
| 6. | Resolution | 1mm |
| 7. | Scan angle | 240° |
| 8. | Angular resolution | 0.36° |
| 9. | Scanning speed | 100msec/scan |
| 10. | Dimension (W×D×H) | 50×50×70mm$^3$ |
| 11. | Weight | Approx. 160 g |
| 12. | Ambient(Temperature / Humidity) | -10 ~ 50 ºC / 85%RH or less (without dew and frost) |

## III. PROCEDURE FOR DATA ACQUISITION

The laser requires using the URG Benri V1.2.5 by HOKUYO Automatic Co, downloaded from the Acroname download section. The laser has two ports, one USB and power source. After giving the proper connection at the ports, the software must be installed after checking for compatibility with the operating system. After installation, the program should be opened and the refresh button must be clicked near the data source icon in the SERIAL connection Tab. The laser will start taking the readings when the connect button is clicked which is next to the refresh button. The readings will be shown in the screen as green area and it is to be noted that each circle in the background grid is a distance of 1m. Then by using the play-pause-stop controls below, the reading time can be adjusted and the icons above the main reading page enable the user to take snapshots of the readings for further reference.

## IV. EFFECT OF TARGET SURFACE PROPERTIES

Characterization of the Hokuyo URG-40 LX LRF was done with regard to difference in the reflectance properties of different specimens. To calculate the error in range and width (parallel distance) measurements, test was conducted on various specimens with varying properties and dimensions.

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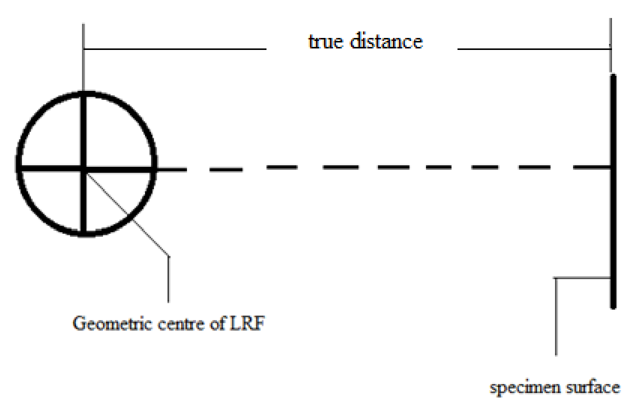


Figure: 3. Experimental Setup

The following specimens have been used for the measurements.

Table: 2. Specimen details

| Specimen No. | Name of the Specimen |
|---|---|
| 1. | Brass cylinder |
| 2. | Glass fiber |
| 3. | Steel bar |
| 4. | Poly vinyl chloride ( red color) |
| 5. | Aluminum |
| 6. | Plexiglas |
| 7. | Poly vinyl chloride ( grey color) |
| 8. | Carbon fiber (grey / black color) |
| 9. | Aluminum bar |
| 10. | Teflon (white) |
| 11. | Wooden block |
| 12. | Aluminum block (polished) |
| 13. | Copper plate |
| 14. | Poly vinyl chloride ( bar – grey color) |
| 15. | Concrete block |
| 16. | Rubber |
| 17. | Glass |

The specimens were placed at 1m or 2m from the LRF. The true distance was taken as the distance measured from the geometric center of LRF to the specimen, since reference point for the range measurement is not specified by the manufacturers. Then a comprehensive scans of 300 in number were done and the average measured range was tabulated. Comparing the later with the former value (measured to true distance) percentage of error was found. The table below illustrate the evaluated average distance and the percentage of error for 14 (at a distance of 1m) and 16 (at a distance of 2 m) tabulated specimens, each being kept at the fixed distance respectively from the LRF. It is to be noted that this fixed distance is the true distance. The following tables show the results for the measurements at a fixed distance of 1m (Table-3) and distance of 2m (Table-4).

Table: 3. Error details

| S.No | Specimen number | Error range (%) | |
|---|---|---|---|
| 1. | 1 | -6.0 | +2.0 |
| 2. | 2 | -1.0 | +1.0 |
| 3. | 3 | -2.0 | 0 |
| 4. | 4 | +2.0 | +3.0 |
| 5. | 5 | +5.0 | +6.0 |
| 6. | 7 | -5.0 | -7.0 |
| 7. | 8(A) | -8.0 | +6.0 |
| 8. | 8(B) | -9.0 | +3.0 |
| 9. | 9 | 0 | +5.0 |
| 10. | 10 | +2.0 | +3.0 |
| 11. | 11 | 0 | 0 |
| 12. | 12 | +7.0 | +16 |
| 13. | 13 | +9.0 | +20 |
| 14. | 14 | -2.0 | -5.0 |

Table: 4. Error details

| S.No | Specimen number | Error range (%) | |
|---|---|---|---|
| 1. | 1 | -1.0 | +0.5 |
| 2. | 2 | -1.5 | +2.0 |
| 3. | 3 | +1.0 | +2.5 |
| 4. | 4 | +0.5 | +1.5 |
| 5. | 5 | +2.5 | +3.5 |
| 6. | 7 | -1.5 | +1.5 |
| 7. | 8(A) | -2.5 | +2.5 |
| 8. | 8(B) | -0.5 | +3.5 |
| 9 | 9 | +1 | +2.5 |
| 10. | 10 | 0 | +1.0 |
| 11. | 11 | 0 | +0.5 |
| 12. | 12 | +1.5 | +3.0 |
| 13. | 13 | +1.5 | +4.0 |
| 14. | 14 | -1.0 | -2.5 |

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It is to be noted that the tabulated specimens have different surface properties. The test was conducted to evaluate the behaviour of the laser with difference in the surface of the specimen. It was found that the specimens with glossy surfaces (like specimen 1, 9, 12) give sharp peak at the centre as shown below, thereby increasing the positive error.

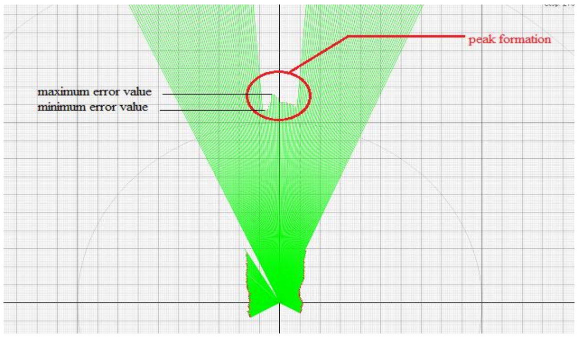


**Figure: 4. Sample reading for specimen 12 (AL block of dimension 150mm)**

The visible region is denoted by the green color and obstructions if any is read by the laser in a straight line and the obstruction area would be denoted by the pattern in the green region thus showing the obstruction area in the plain surface, the pattern obtained is not straight but irregular due to the phenomenon of surface reflection. With higher peak formation the error measured is also high when compared to the other specimens. It is to be noted that error in measured distance decreases as the true distance increases. The error measured for each specimen as a function of true distance (a constant true distance) varies as the specimen varies. The peak formation depends upon true distance and size of the object. Peak formation inversely varies with the true distance, i.e. as the true distance increases the tendency of peak formation decreases. Also as the size of object increases, the peak formation decreases. When used to find the range of a glossy surface such as copper, aluminum or brass, the tendency for the peak formation increases. This is evident from the graphs below. Below this you can find the graphs for glossy material such as aluminum, copper and glass. Also for comparison non glossy surface such as wood, steel has been included to understand the comparison.


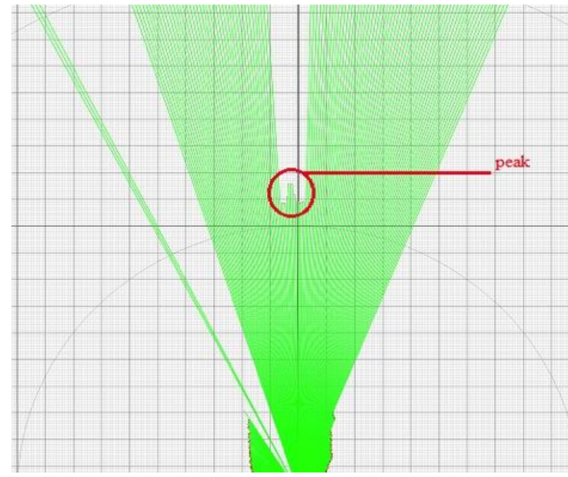


**Figure: 5. Sample reading for specimen 13 (copper plate of dimension 68mm)**

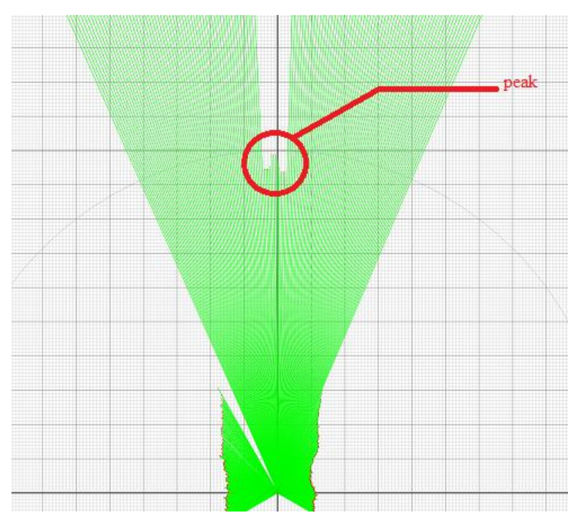


**Figure: 6. Sample reading for specimen 1 (brass of diameter 80mm)**

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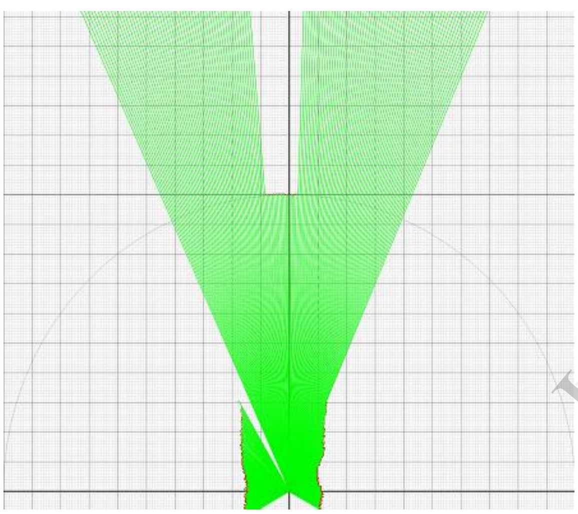

**Figure: 7. Sample reading for specimen 11 (wooden cube of dimension 100mm)**

As seen in the above pictures, it is evident that when the view of the laser is narrowed using a cardboard box or something, the resolution and accuracy is good due to the less amount of interference and pixilation. Also it is evident that on non glossy surfaces like wood and steel there is no peak formation and accuracy is good.

**Image: 1 (a+b). Cabin**

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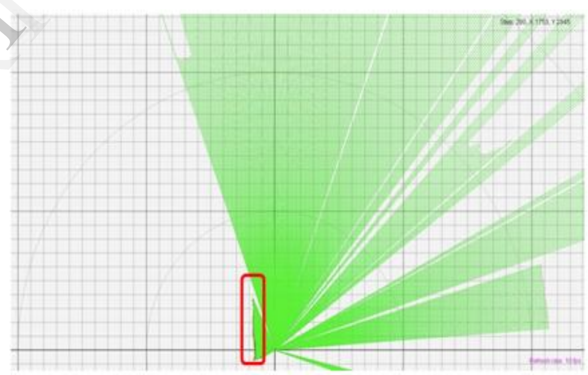

**Figure: 8. Sample reading for the Cabin (Image-1) when laser view is narrowed by Cardboard**

It can also be observed in the table that the reading for specimen 6 (transparent Plexiglas) and for specimen 17 (transparent glass) has not been taken. The specimen 6 and the specimen 17 couldn't be read by the particular LRF and on scanning these two specimens the reading thus obtained did not show any shape or obstruction. Rather it made the LRF go blind at some angle and the image obtained for these two specimens were similar to the image obtained on scanning the cabin (Image- 2) without narrowing the vision of the LRF.

**Image: 2. Cabin**

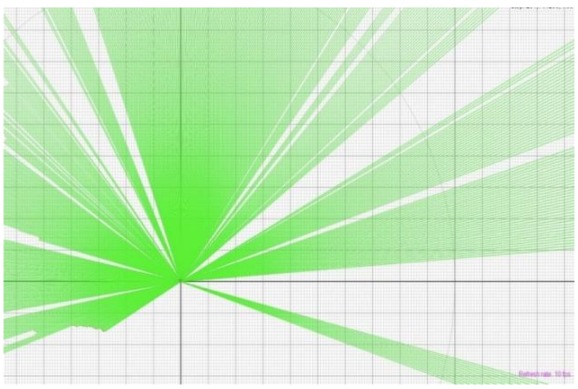

**Figure: 9. Sample reading for the Cabin (Image-2)**

When the laser is to be used for indoor purposes, it is to be noted that the view/vision of the laser must be limited to a narrow angle. If not the accuracy of the image read by the laser would be low due to interference. Also the error of the irregular shape reading increases with increase in irregularity.

## CONCLUSION

By the extensive tests conducted on the HUKOYO URG-04LX LRF, some conclusions were attained. The conclusions made from the evaluation are listed below.

1. Maximum error range for distances <1000mm was found to be in the range of ±9%.
2. Maximum error range for distances >1000mm was found to be in the range of ±4%.
3. It was specifically observed that on glossy surfaces the error range was particularly very high in the range of ±20% (for distances <1000mm) and this infers that the laser is practically incapable for accurate ranging of glossy surfaces.
4. The problem of peak formation was found to be dependent on the distance from the laser, the surface property of the specimen & size of the specimen.

4.1 On non glossy surfaces the peak formation was low, while the tendency of peak formation was especially high when the surface of the specimen was glossy

4.2 It was also observed that with increase in true distance of the specimen, it was found that the error decreases and for glossy surfaces peak formation decreases.

4.3 It was observed that as the size of the specimen increases, the tendency of peak formation decreases, and also error decreases.

5. It was also observed that the laser is incapable of ranging when the vision range is high as it led to increase in error % due to interference.
**6.** A physical method of narrowing the view of the LRF was required to have optimum ranging characteristics of the laser as narrowing reduced the interference in the laser and subsequently increasing the accuracy of ranging.
**7.** It was also observed that the laser is incapable of reading materials such as Plexiglas and glass. The laser seemed to pass through the material and thus not reading the aforementioned materials.

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