Characterization of Hokuyo UTM-30LX Laser Range Finder for an Autonomous Mobile Robot

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Abstract. One of the most common problems of autonomous mobile robots is object avoidance in a dynamically changing environment. The effectiveness of algorithms responsible for trajectory planing is largely dependent on the correct sensory input. It is necessary to equip a mobile robot with the proper sensors to allow a correct functioning in unknown terrain. With the high degree of complexity standard point distance sensors are insufficient for high speed movement. The recent development of compact laser range finders allowed the minimization of robot dimensions. Hokuyo UTM-30LX is an example of such a sensor. For a precise understanding of the measurements, a characterization of a sensor is needed. This paper is summarizes the parameters of Hokuyo UTM-30LX laser range finder, in particular: drift effect, influence of target distance, surface brightness, color and material, and the sensor orientation. The parameters measured prove that the Hokuyo UTM-30LX can be used in a mobile robot system for complex object detection and avoidance.

Keywords: laser range finder, Hokuyo UTM-30LX, autonomous mobile robot, object avoidance.

1 Introduction

The constant increase in computing power of microcontrollers is allowing mobile robots to become more and more intelligent. With the higher degree of complexity in the control algorithms a certain level of autonomy can be achieved. One of the general, and yet the most profound functions of any mobile robot is movement.

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It consists of several problems depending on the type of the robot. Wheeled mobile robots, humanoids or even UAVs face the problem of object avoidance. Although the problem can be simplified for a preprogrammed environment, missions in real, dynamically changing terrain require a higher degree of knowledge of the surroundings.

The effectiveness of algorithms responsible for trajectory planing is largely dependent on the correct sensory input. An autonomous robotic platform must be equipped with distance sensors to allow object avoidance. With more complex environments like any outdoor terrain, standard point distance sensors are insufficient at high speeds. The solution lies with 2D and 3D laser range finders. An example of such a device is the Hokuyo UTM-30LX. With it's compact size it fits well in a mobile robotic platform, presented of Fig. 1.

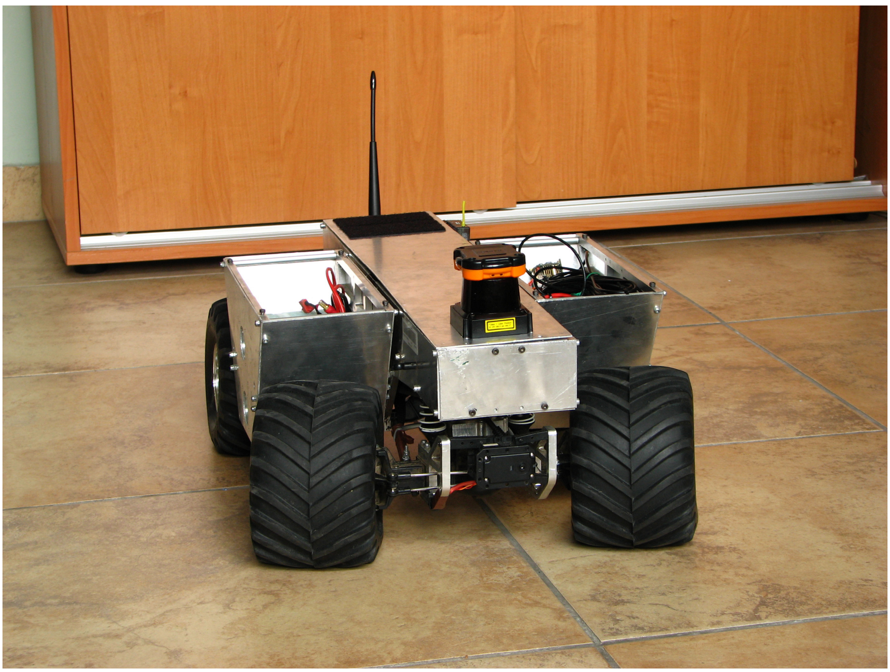

Fig. 1 Autonomous robotic platform with Hokuyo UTM-30LX installed

To use any laser range finder, like UTM-30LX, in changing environments it is necessary to measure the influence of external conditions on the result. In the research done, Hokuyo laser range finder has been tested for: the drift effect, influence of target distance, surface brightness, color and material, and the sensor orientation.

The following measurements has been done to test the validity of using Hokuyo UTM-30LX on a mobile, wheeled robotic platform shown in Fig. 1.

2 Characterization of Laser Range Finders

The need of more accurate characterization of laser range finders was expressed in many works, including Desai et al [1], which expressed the need of proper selection of the device for best quality of measurements in performed task, or Pascoal et al [2], in which range finders were evaluated for their usefulness in specific mission. The specifications provided by the sensor's producer defines only general information about the device's accuracy and does not include details, such as the impact of different materials and colors on the measurement surface, drift effect, or the accuracy on different distances.

As autonomous vehicles are designed to operate in variety of environments, these characteristics need to enable the designer to predict possible inaccuracy of measurement and minimize it's impact on the vehicle's operation. In the most extreme situations, the device might not be able to detect certain materials. Pascoal et al in [2] showed, that Hokuyo URG-04LX was unable to detect black velvet, while Sick DT60 and IFM O1D100 results had a large error when detecting a reflective surface, such as a mirror.

Characterization of the device can also be used to create its model, either for calibration or simulation purposes. Propositions of such models were presented for other range finders: for Sick LMS 200 by Ye and Borenstein [3], and for Hokuyo URG-04LX by Kneip et al [4] and for UBG-04LX-F01 by Park et al [5].

3 Hokuyo UTM-30LX

Hokuyo UTM-30LX provides scanning range of 270° and 30 meters with angular resolution of 0.25° per step. It is able to measure distances up to 60 meters, but without guaranteed reliability. One full scan cycle lasts for 25 ms, which supplies a 40 Hz measurement frequency. Data transfer to host is realized through USB 2.0 interface, using dedicated SCIP 2.0 protocol in communication with device. Therefore it is necessary for robotic platform to implement such interface. It has been done using FTDI VNC1L 'Vinculum' USB Host Controller, which bridges the signal to STM32F microcontroller. This allowed the implementation of Ethernet (with provided Ethernet PHY) or CAN based communication onboard the mobile robot.

The measurement accuracy, according to the producer [11], is defined as ± 30 *mm* at 0.1 to 10 *m* range, and ± 50 *mm* at 10 to 30 *m* range. Precision of the repeated measurement, defined as a standard deviation of samples, is defined as less than 10 *mm* at 0.1 to 10 *m* range, and less than 30 *mm* at 10 to 30 *m* range. All those values apply to the measurement of white sheet.

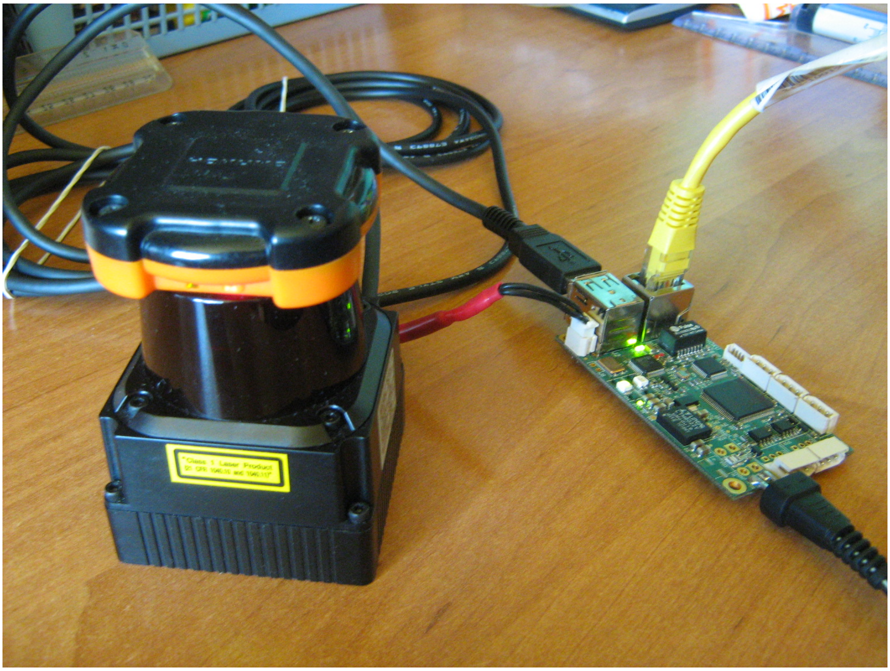

Fig. 2 The setup of UTM-30LX device connected with STM32F based board with Ethernet connection to development computer

4 Results

All of the experiments were performed using the measurement on the front step of UTM-30LX, i.e. measurement of the single point located in front of the device.

For reception, processing and presenting data on host, the LabVIEW virtual instruments were used. Hokuyo provides the UTM-30LX driver for Windows and driver for their scanning laser devices for LabVIEW, therefore quick development of the testing applications was possible.

Nominal distance was measured, using Bosh DLE 70 Laser Rangefinder. It has typical measurement accuracy of $\pm 1.5\ mm$, which is one order of magnitude better than UTM-30LX, therefore it gives good reference distance value.

In each of the experiments, at least 1000 samples were taken. Result values formed a single, Gaussian-like lobe on the histograms.

The following subsections show the results of UTM-30LX characterization.

4.1 Drift Effect

To determine the measurement drift over time, the scanner was placed at about 2 meters distance from solid wall and set to make single measurement every half second. Before that, the device was powered off for at least 4 hours. The experiment was run for over 100 minutes in stable environment (i.e. ambient temperature and lighting). There was no need of more frequent sampling or more accurate distance referencing, as the drift was expected to be observed over longer than few minutes period and it should have approximately the same effect, regardless of the measured distance.

As shown on Fig. 3, during first 45 – 50 *min* of operation the measurement is rising about 8 – 10 *mm*. Two more repetitions of this tests confirmed the result.

To exclude drift effect from other tests, the device was running for at least 1 hour before each experiment.

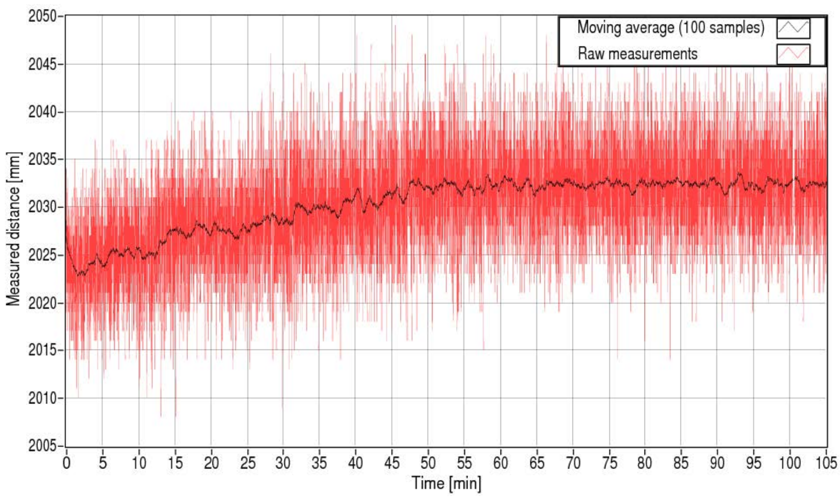

Fig. 3 Observed drift effect of measurements over time. Samples values are rising during the first 45 – 50 *min* of measurements.

4.2 Target Distance

Work of Kneip et al. [4] showed connection between measurement accuracy and distance of scanning device from the target. Park et al. [5] proposed also the investigation of relationship between standard deviation and distance. To determine those dependencies, 1000 samples were taken at every 2 meters distance, beginning at 2 *m*, up to 22 *m*, then mean value and standard deviation of measurements at each distance was calculated.

Standard deviation of measurements is rising with distance, as shown on Fig. 4. This relationship can be approximated with linear function. The most probable source of this effect is the increasing dissipation of laser light, resulting in lower intensity of captured reflection at higher distances. Such relationship was not so clearly observable in Parks et al. work, because of much shorter range of their measurements (only 91 – 4992 *mm*).

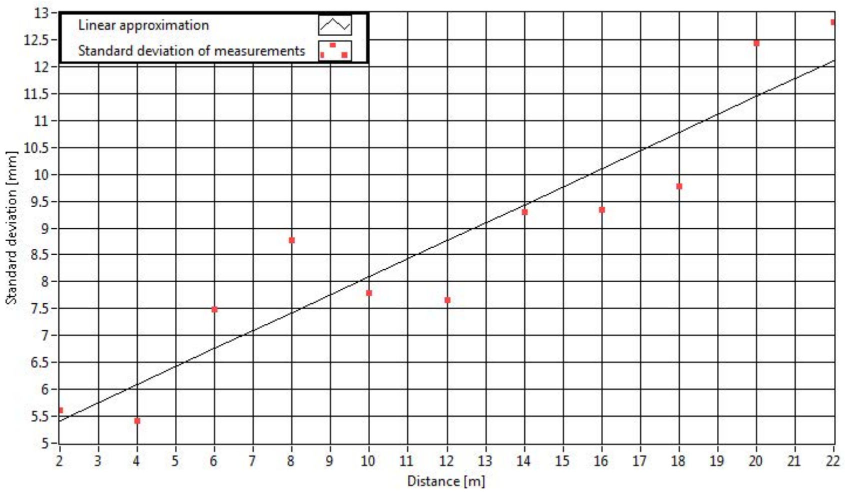

Fig. 4 Standard deviation of measurements over rising distance from target. Linear approximation was made using least squares method.

Absolute error, shown in Fig. 5, is not connected with the distance in any clear relationship, despite indication in device specification that accuracy at distance higher than 10 *m* should become worse. It is oscillating between −18 and 18 *mm*. As result, relative error is starting from 0.7% for 2 *m* and tending towards nearly 0% with increasing nominal distance.

4.3 Target Surface Brightness, Color and Material

The influence of target surface brightness and color was tested by placing the sheets of different brightness and colors at 1.5 meters distance from UTM-30LX. 5000 samples were taken with each brightness and color. Histograms of each series are shown in Fig. 6 and Fig. 7.

On the contrary to results of similar experiments performed with Hokuyo URG-04LX [4] and Hokuyo UBG-04LX-F01 [5], no clear relationship between surface

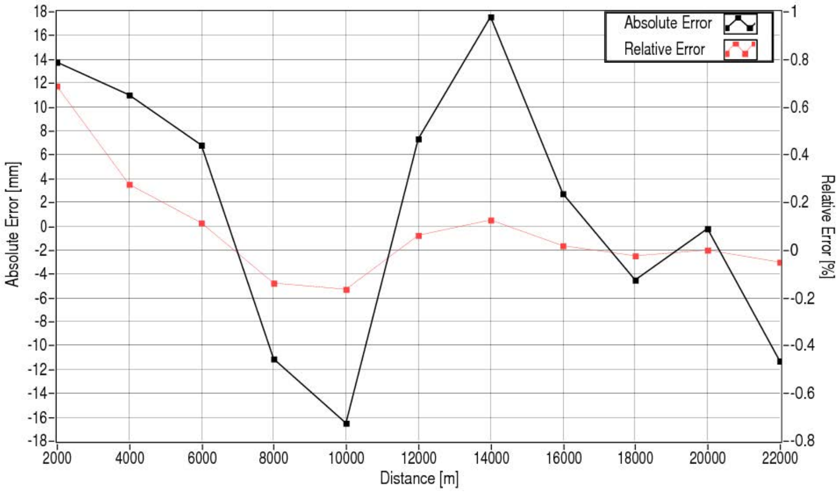

Fig. 5 Absolute error of measurements over rising distance from target

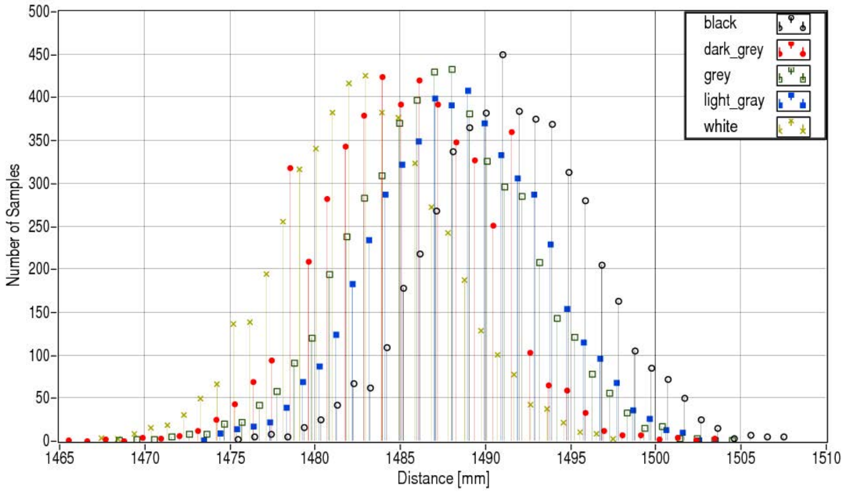

Fig. 6 Effect of brightness of target

brightness or color and samples values were showed for UTM-30LX. While the placement of histogram lobes for different brightness or colors can be distinguished for other devices, those lobes for UTM-30LX are nearly laying on each other. One possible explanation might be nearly six times higher range of UTM-30LX, which would mean higher energy of emitted laser light, so captured reflection should have better intensity, as the effect of scattering light on target surface at lower distances should be relatively less significant.

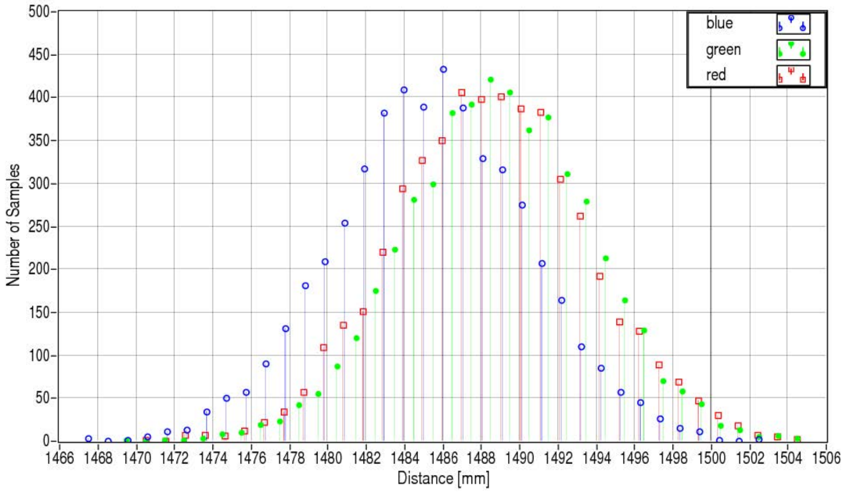

Fig. 7 Effect of color of target

Standard deviation and errors of measurements are shown in Table 1. Highest relative error was noted for the brightest (white) sheet: -1.14%, and lowest for black sheet: -0.56%. As for the surface color, green and red sheet was measured with same relative error of -0.77%, and blue sheet with slightly higher error of -0.97%. Most notably, all errors for color and brightness were negative.

The device showed very stable precision at this distance, disregarding target color and brightness, as standard deviation for each brightness and color is similar, oscillating around $4.80mm$.

Table 1 Summary of the measurements of different surface brightness and colors

	Absolute error [mm]	Relative Error [%]	Standard Deviation [mm]
White	-17.14	-1.14	4.83
Light Grey	-11.619	-0.77	4.87
Grey	-12.75	-0.85	4.80
Dark Grey	-14.78	-0.98	4.74
Black	-8.48	-0.56	4.87
Blue	-14.61	-0.97	4.86
Green	-11.59	-0.77	4.82
Red	-11.56	-0.77	4.87

Similar experiments were performed with different target materials. Chosen materials were: aluminium plate, steel plate with rougher surface, compact disk as example of very reflective material, moderately reflective plastic plate (green color), cotton cloth and wooden plank. The key to choose such materials were to check the effect of materials which might be meet by the device during operation on autonomous robot (wood, metal, clothes), or specific materials (CD, plastic).

Results of the experiment (Table 2) shows that reflectiveness of the material has the biggest impact on measurement accuracy and precision. The measurement of compact disk came with relative error of 1.82% and standard deviation of 9.13 *mm*, which are much higher than in any other performed experiment.

Table 2 Summary of the measurements of different materials

	Absolute error [mm]	Relative Error [%]	Standard Deviation [mm]
Aluminium	-6.74	-0.44	4.75
Steel	7.70	0.38	5.03
CD	27.39	1.82	9.13
Cotton	12.75	0.63	4.73
Wood	4.24	0.21	4.76
Plastic	7.25	0.36	5.10

4.4 Scanner Orientation

During operation in natural environment, scanner might be put in various orientations when robot is moving on rough terrain. This may influence the measurement, as gravity would have different impact on rotation of the sensor.

The experiment included measurements of target at 1.5 *m* distance from the device in four orientations: up (normal orientation), right (rotation of 90 deg,

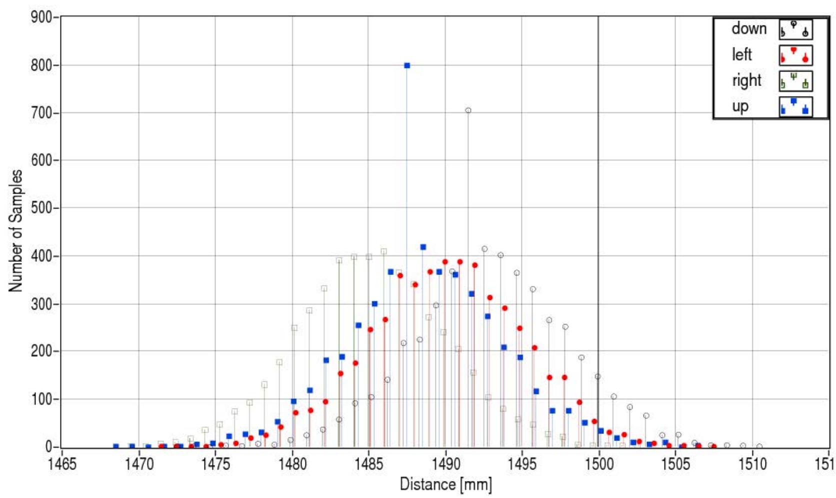

Fig. 8 Effect of orientation of the device

relative to normal orientation when looking from behind the device), down (rotation of 180 deg) and left (rotation of 270 deg). For each orientation 5000 samples were taken.

The most accurate measurements were made when the device was in 'down' orientation, with relative error of measurement of -0.47%, while the highest error was recorded in 'right' orientation: -0.99%. However, 'right' orientation also showed the least standard deviation of 4.95 *mm*, and the highest was for 'left': 5.11 *mm*. The differences in accuracy and precision for different orientations can be compared to those from the experiments with different colors and brightness.

5 Conclusions

The experiments performed and presented in this article have determined the usability of UTM-30LX laser rangefinder in autonomous mobile robots.

Results show that Hokuyo UTM-30LX can be used for distance scanning, targeting different materials, colors and brightness with similar effects. The relative errors of measurements were within $\pm 1\%$ and standard deviation was less than 5 *mm*. Such precision and accuracy is sufficient for usage in object avoidance algorithms. Caution must be taken only during measurements of highly reflective surfaces, because of the result higher error and standard deviation.

Because the sensor orientation doesn't have any significant impact on the results, Hokuyo UTM-30LX was positioned on the mobile robotic platform as shown in Fig. 1. It is necessary to take into consideration the influence of distance from the target, as the standard deviation of samples is rising linearly with the distance.

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