# Performance Evaluation of Various 2-D Laser Scanners for Mobile Robot Map Building and Localization

T. Y. Lim[1], C. F. Yeong[2], E. L. M. Su[3], S. F. Chik[3], P. J. H. Chin[4], P. H. Tan[4]
[1]*Malaysia Japan Institute of Technolgy (MJIIT), Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor, Malaysia.*
[2]*Centre for Artificial Intelligence and Robotics, Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor, Malaysia.*
[3]*Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor, Malaysia.*
[4]*DF Automation and Robotics Sdn. Bhd, Taman Impian Emas, 81300 Skudai, Johor, Malaysia.*
*cfyeong@utm.my*

***Abstract*—A study has been carried out to investigate the performance of various 2-D laser scanners, which influence the map building quality and localization performance for a mobile robot. Laser scanners are increasingly used in automation and robotic applications. They are widely used as sensing devices for map building and localization in navigation of mobile robot. Laser scanners are commercially available, but there is very little published information on the performance comparison of various laser scanners on the mobile robot map building and localization. Hence, this work studies the performance by comparing four laser scanners which are Hokuyo URG04LX-UG01, Hokuyo UTM30LX, SICK TIM551 and Pepperl Fuchs ODM30M. The results, which are verified by comparison with the reference experimental data, indicated that the angle resolution and sensing range of laser scanner are key factors affecting the map building quality and position estimation for localization. From the experiment, laser scanner with 0.25° angle resolution is optimum enough for building a map of sufficient quality for good localization performance. With 30meter of sensing range, a laser scanner can also result in better localization performance, especially in big environment.**

***Index Terms*— Laser Scanner; Specification; Map Building; Localization; Performance Evaluation.**

## I. INTRODUCTION

Robotic application is on the rise in the field of manufacturing and service industry. A reliable perception of the environment is crucial in robotic applications especially for autonomous navigating system. An autonomous navigating system, which moves in complex everyday environment and interacts with humans, has to monitor multiple aspects of the environment for reliable navigation [1]. For a ground driven mobile platform, 2D laser scanner is the most commonly used sensor in the environment perception or detection. The laser scanner provides all information to derive an appropriate geometric map of the environment that is ready for localization, trajectory planning and movement tasks. According to Carmer [2], the information derived from the laser scanner is useful in several algorithms such as filtering, map building and localization. It has been widely used in localization [3, 4], dynamic map building [5, 6] and collision avoidance [7].

A laser scanner is a high cost sensor and there are many types of laser scanners with variety of specifications in the current robotic community. The selection of the laser scanner is important as it affects the overall navigation performance but is difficult due to the variations in each sensor specification. The performance of the laser scanner can be influenced by the specification. The parameters typically listed in the specification include minimum and maximum measurement distance, measurement accuracy, field of view, scan rate and angle resolution. Hence, the main work from this paper is to investigate how the performance of each specification parameter of the laser scanner can affect robot map building and localization performance.

Mapping is the process of creating a spatial model of the environment surrounding the robot [8]. The map is then used for localization and navigation. Localization tells the robot where it is in relation to the environment [8]. Mapping can be done using laser scanners.

Four types of laser scanners are chosen for this performance evaluation, which are URG-04LX-UG01 and UTM-30LX from Japanese company Hokuyo [9], TIM551-2050001 from German company Sick [10] and OMD30M-R2000 from German company Pepperl Fuchs [11]. In Section II, a technical comparison of the laser scanners is presented and discussed, whereas in Section III, the experiment setup is described. An evaluation of the mapping and localization performance is also discussed in Section IV.

## II. TECHNICAL COMPARISON

Laser scanner emits an infrared beam and a rotating mirror changes the beam's direction. Laser hits the surface of an object and is reflected [12]. The direction of reflected light is changed again by a rotating mirror, and captured by the photo diode [12]. The phases of the emitted and received light are compared and the distance between the sensor and the object is calculated [12]. Table 1 summarizes the technical properties of four popular scanner types. The selection of the laser scanners is based on their sensing range, angle resolution, brand and price.

Table 1
Summary of Technical Properties of Four Selected Laser Scanners

| Sensor |  HOKUYO URG-04LX-UG01 |  SICK TIM551 |  HOKUYO UTM-30LX |  PEPPERL FUCHS OMD30M-R2000 |
|---|---|---|---|---|
| Distance (m) | 0.06 – 4.10 | 0.05 – 10.00 | 0.10 – 30.00 | 0.10 – 30.00 |
| Accuracy (m) | 0.06 - 1.00: ± 0.03<br>1.00 - 4.10: ±3% | ± 0.06 | 0.10 - 10.00: ±0.03<br>10.00 - 30.00: ±0.05 | 0.01 |
| Field of View (°) | 240 | 270 | 270 | 360 |
| Scan Rate (Hz) | 10 | 15 | 40 | 50 |
| Steps per Scan | 1024 | 360 | 1440 | 250000 |
| Angle Resolution (°) | 0.360 | 1.000 | 0.250 | 0.014 |
| Price Group | Low | Medium | High | Higher |

### *A. Hokuyo URG04LX*

URG04LX has a sensing distance between 0.06 m and 4.10 m when the object is white in surface. The measurement accuracy is ±30 mm for distances of less than 1 m. Its rotating mirror can sweep 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 10 Hz. It is considered as low priced among the four laser scanners.

### *B. Sick TIM551*

Sick TIM551 can measure distance between 0.05 m and 10.00 m. It has an accuracy of ±60 mm in distance measurement. The laser scanner has a field of view of up to 270° with angular resolution of 1°. The scanning frequency is 15 Hz. It is priced as medium range laser scanner among the four laser scanners.

### *C. Hokuyo UTM30LX*

Hokuyo UTM30LX is widely used in industry and research field as it has the capability of measuring distance from 0.1 m to 30.00 m. The accuracy of the measurement is ±30 mm for distances of less than 10m and ±50 mm for distances of less than 30m. The field of view of the laser scanner is 270° with angle resolution of 0.25°. The scan rate of the sensor can go up to 40Hz. It is a high priced laser scanner.

### *D. Pepperl Fuchs OMD30M*

Another laser scanner with high specification is the Pepperl Fuchs OMD30M. OMD30M has distance measurement from 0.1 m to 30 m. The accuracy of the measurement is ±10 mm. It has a full 360° viewing angle with the angle resolution up to 0.014°. The scanning frequency is 50Hz. It is the highest priced among the four laser scanners.

## III. Experiment Setup

The presented work was implemented on a mobile robot with Robot Operating System (ROS). Experiments were designed to compare the map building quality produced by each of the laser scanners in real environments as well as using the map produced to compare the localization performance by using "*Stage*" simulation from ROS.

### *A. Mapping*

In this experiment, the mapping algorithm used was the Gmapping algorithm. Gmapping is a highly efficient Rao-Blackwellized particle filler to learn grid maps from laser scanner data.

A mobile robot is built by using a Kobuki platform (ROS supported). Figure 1 shows the mobile robot and the placement position of the laser scanner, is indicated by the red box. In order to build the map using the robot, the process as shown in Table 2 is carried out to obtain the best map representation from each laser scanner. There is also a reference map constructed manually, which represents the ideal map building from the environment.

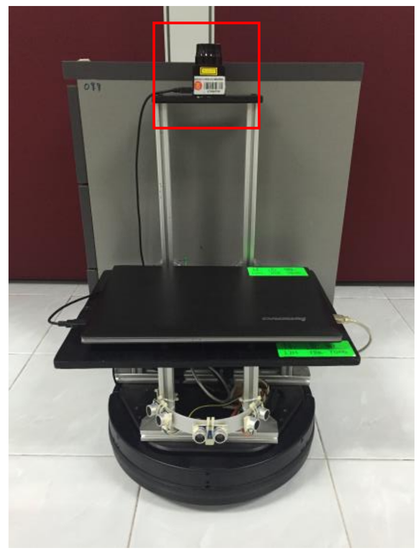


Figure 1: Mobile robot with Kobuki platform and laser scanner.

Table 2
Steps for Running Mapping Experiment

| Steps for running mapping experiment |
|---|
| 1. Bring up the ROS System. |
| 2. Bring up the Kobuki platform. |
| 3. Bring up the driver of the sensor being used. |
| 4. Start Gmapping. |
| 5. Save the map. |
| 6. Steps 1 – 5 are repeated to obtain three maps. |
| 7. Best map with less noise and high accuracy is selected. |

### *B. Localization*

The localization algorithm used in the experiment is Adaptive Monte Carlo Localization (AMCL). AMCL implements the adaptive (or KLD-sampling) Monte Carlo localization approach, which uses a particle filter to track the pose of a robot against a known map [13].

The experiment was carried out using the *Stage* simulation from ROS. *Stage* is a 2D robot simulator. It provides a virtual world populated by mobile robots and sensors, along with various objects for the robots to sense and manipulate. *Stage* simulates a world as defined in a *world* file. This file used the map built from the map building experiment to tell *Stage* everything about the world. The process of running this experiment is described in Table 3.

Table 3
Step for Running Localization Experiment

| Steps for running localization experiment |
|---|
| 1. Stage simulator is loaded with sensor model with its respective map built. |
| 2. Start AMCL and navigation package in ROS. |
| 3. Robot is fixed at its initial position. |
| 4. Robot is asked to travel a path to its desired position. |
| 5. The localized position is collected along the path. |
| 6. Steps 3-5 are repeated five times to get the average localized position. |
| 7. Steps 3-6 are repeated with another two different paths. |
| 8. Steps 1-7 are repeated using different sensor model with its respective map built. |
| 9. All the average localized positions from three different paths and from four different sensors as well as from a reference map are interpolated into 100 sample points for analysis. |

## IV. Results and Discussion

### *A. Map Building Comparison*

Figures 2(a) until 2(e) show the best map building results from each of the laser scanner. From observation, the four laser scanners managed to build the map similar to the reference map. The resolution of all the maps built is 0.1meter/grid or 0.1meter/pixel in an image. The reference map, which is based on the blueprint of the environment is drawn manually with 0.1meter/pixel. The mappings produced by both the Hokuyo UTM30LX and Pepperl Fuchs OMD30M seems to have similar quality.

There are slight noises produced by the Hokuyo URG04LX. However, the map built by SICK TIM551 contains a lot of noise and the quality is apparently lower compared to the other three mappings. This might be due to the poorer angle resolution of SICK TIM551 (1°). Hence, from this it can be concluded that the quality of the map building depends on the angle resolution of laser scanners. An angle resolution of 0.25° is optimum enough for building a map.

### *B. Localization Comparison*

The first localization experiment is to assign the robot to move a straight line for 6 meters as shown in the Figure 3(a). The second localization experiment is to assign the robot to move along a curve with a lot of features along the path. Figure 3(b) shows the described path.

The purpose of this experiment is to eliminate the limitation of range capability of laser scanners and analyze their performance. The last localization experiment has longer and more complex path. The path is shown in Figure 3(c). The purpose of this experiment is to investigate the localization performance when a robot has to travel along a long path.

The estimated position of four localization performances from four different laser scanners, with their respective mapping is collected. The positions collected from reference map are used as reference positions. The collected positions are interpolated into 100 points and the difference between the reference positions and estimated positions for each point are computed. Finally the cumulative error is obtained from all the points. The higher the cumulative error, the poorer the localization performance.

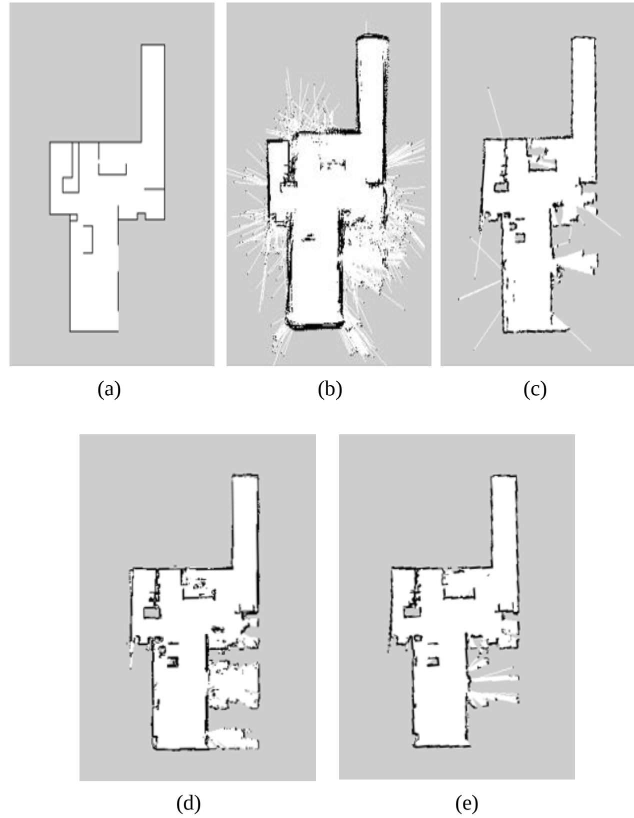
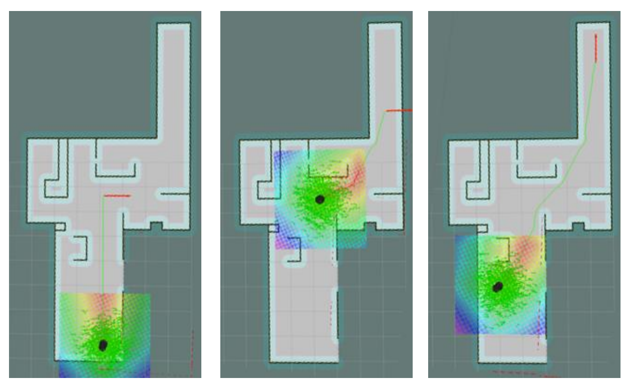



Figure 2: (a) Reference map drawn manually. (b) Map built by Sick TIM551. (c) Map built by Hokuyo URG04LX. (d) Map built by Hokuyo UTM30LX. (e) Map built by Pepper Fuchs OMD30M



(a) (b) (c)

Figure 3: (a) Experiment with straight line path. (b) Experiment with short curve path. (c) Experiment with complex and long path.

#### *a. Straight Path*

The result of this experiment is shown in Figure 4. The localized position from simulated Hokuyo URG04LX and its built map shows poorest result compared to the other three laser scanners. This might be affected by the range limit from the laser scanner. The distance along the path is more than the range capability of the laser scanner, which results in inaccurate estimated position.

The other three laser scanners have similar estimated position. TIM551 has the second poorest result and this might be due to the poor quality of the map building by itself. From this experiment, with the limited sensing range from laser scanner, it would affect the localization performance, hence the range measurement of laser scanner is important.

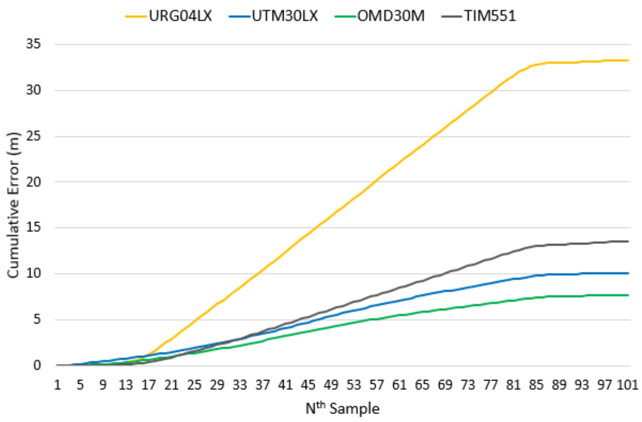



Figure 4: Cumulative error results from each of laser scanners.

### b. Short Curve Path

The comparisons of cumulative error results are shown in Figure 5. Both URG04LX and TIM551 shows similar end results while both UTM30LX and OMD30M shows another set of similar end results, which is better than the former set. In fact when looking at the cumulative error along the path, URG04LX, UTM30LX and OMD30M show similar good performance in the beginning until the middle of the path. The estimated position by URG04LX started to lose its accuracy from the middle of the path. This might be due to the environment around the end path, which is longer and the range capability of URG30LX cannot handle it. The experiment shows that poor mapping affects localization performance, hence angle resolution of laser scanner is important.

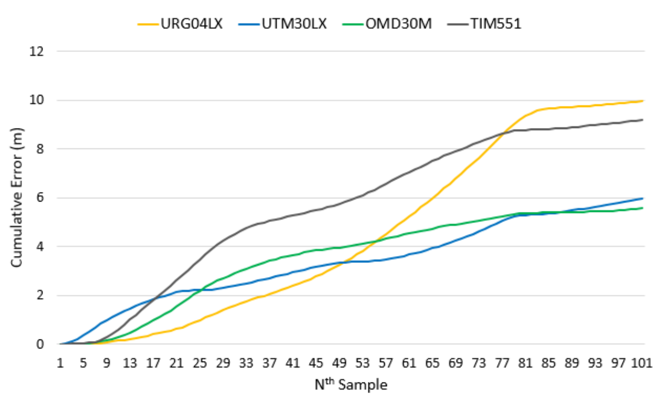



Figure 5: Cumulative error results from each of laser scanners.

### c. Long and Complex Path

The results from 4 different laser scanner for the long and complex path are shown in Figure 6. Experiment result shows that the OMD30M can give accurate result with the least cumulative error among the four laser scanners although both the OMD30M and UTM30LX has same sensing range with OMD30M having higher angle resolution. Based on the specification, the OMD30M can sense more accurate feature hence, should result in better position estimation.

The URG04LX has better position estimation in the beginning but poorest estimation in the end. Both the sensing range and the angle resolution of laser scanner are crucial in getting a good localization performance. In order to get a stable localization performance along the path, these two parameters of the laser scanner must be taken into consideration.

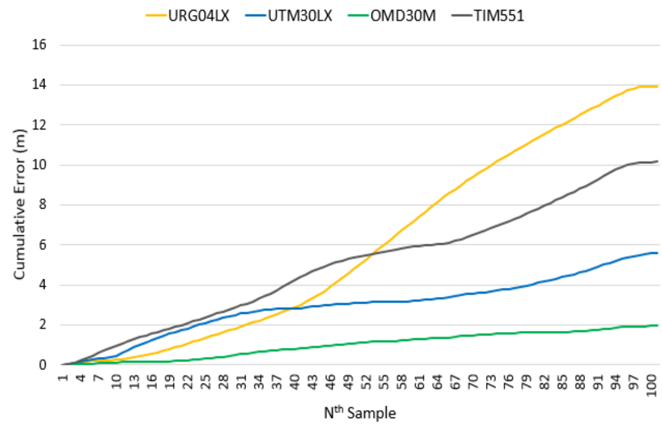



Figure 6: Cumulative error result from each of laser scanners

### d. Overall Performance

From all the results obtained, OMD30M from Pepperl Fuchs shows the best performance for localization performances due to its highest specification among the four laser scanners, but it is also the most expensive laser scanner among the four. The performance from Hokuyo UTM30LX is shown to be good enough for map building and localization at lower cost compared to the OMD30M.

## V. Conclusion

An investigation of laser scanner performance has been conducted to identify parameters that influence the map building quality and localization performance for a mobile robot navigation. This investigation was run several experiments using a mobile robot with ROS system. From the experiment, it can be concluded that angle resolution of laser scanner is important and it affects the quality of the map building. Better angle resolution from a laser scanner results in a less noisy map.

Quality of the map built for robot localization is very crucial because a noisy map will result in poor position estimation. Besides, with better angle resolution of laser scanner, it can sense more features in the environment, improving position estimation of the mobile robot. With 0.25° angle resolution, laser scanner manages to build a map of sufficient quality and obtain good localization performance. Sensing range of laser scanner is also important because it affects the position estimation, especially when a robot is in a big environment where the laser scanner can hardly sense the features. To be specific, 30 meter of sensing range is able to produce better localization performance.

Overall, Pepperl Fuchs OMD30M produces the best performance in robot localization due to it having the best angle resolution and sensing range.

## ACKNOWLEDGMENT

The authors would like to acknowledge Malaysia-Japan International Institute of Technology, Universiti Teknologi Malaysia for their continuous support. This project is funded by Universiti Research grant 00M81. The authors also thank DF Automation and Robotics Sdn. Bhd. for help in loaning sensor and Kobuki platform as well as sharing technical knowledge.


## REFERENCES


[1] S. Zug, F. Penzlin, A. Dietrich, T. T. Nguyen, and S. Albert, "Are laser scanners replaceable by Kinect sensors in robotic applications?" *IEEE International Symposium on Robotic and Sensors Environments (ROSE)*, 2012, pp. 144-149.

[2] D. C. Carmer, and L. M. Peterson, "Laser radar in robotics." *Proceedings of the IEEE,* 1996, vol. 84, no. 2, pp. 299-320.

[3] I. J. Cox, "Blanche-an experiment in guidance and navigation of an autonomous robot vehicle." *IEEE Transactions on robotics and automation*, vol. 7, no. 2, pp. 193-204, , 1991.

[4] P. Jensfelt, and H. Christensen, "Laser based position acquisition and tracking in an indoor environment." *in International Symposium on Robotics and Automation-ISRA*, 1998, vol. 98.

[5] J. S. Gutmann, W. Burgard, D. Fox, and K. Konolige, "An experimental comparison of localization methods." *IEEE/RSJ International Conference on Intelligent Robots and Systems*, 1998, vol. 2, pp. 736-74.

[6] F. Lu, and E. Milios. "Robot pose estimation in unknown environments by matching 2D range scans." *Journal of Intelligent and Robotic Systems* vol. 18, no. 3, pp. 249-275, 1997.

[7] N. E. Pears, "Feature extraction and tracking for scanning range sensors." *Robotics and Autonomous Systems* vol. 33, no. 1, pp. 43-58, 2000.

[8] S. Zaman, W. Slany, and G. Steinbauer. "ROS-based mapping, localization and autonomous navigation using a Pioneer 3-DX robot and their relevant issues." *IEEE Saudi International in Electronics, Communications and Photonics Conference (SIECPC)*, 2011, pp. 1-4.

[9] Hokuyo Automatic Co. Ltd. Available from: http://www.hokuyo-aut.jp/. Retrieved 22 Jul 2016.

[10] SICK Inc. Available from: https://www.sick.com/us/en. Retrieved 22 Jul 2016.

[11] Pepperl+Fuchs GmbH. Available from: www.pepperl-fuchs.com/. Retrieved 22 Jul 2016.

[12] Y. Okubo, C. Ye, and J. Borenstein. "Characterization of the Hokuyo URG-04LX laser rangefinder for mobile robot obstacle negotiation." *International Society for Optics and Photonics in SPIE Defense, Security, and Sensing*, 2009, pp. 733212-733212.

[13] D. Fox, "KLD-sampling: Adaptive particle filters." *in Advances in Neural Information Processing Systems*, pp. 713-720, 2001.