A Study on the Correction of Non-Linear Bias Error of an Infrared Range Finder Sensor for a Mobile Robot using Neural Network

Je-Goon Ryu¹, Hyeon-Min Shim², Jae-Ho Shin², Eung-Hyuk Lee³, Seung-Hong Hong², and Pyung-Soo Kim³

¹ Intelligence Healthcare System Research Center, Korea Polytechnic University, Korea
doctory@empal.com
² Department of Electronic Engineering, Inha University, Korea
elegage@paran.com
cee@hubdic.com
shhong@inha.ac.kr
³ Department of Electronic Engineering, Korea Polytechnic University, Korea
{ehlee, pskim}@kpu.ac.kr

Abstract. The infrared range finder for a mobile robot has the advantages of the low sensing cost and detecting all objects in front of the mobile robot after sensing. However, it has some non-linear bias errors, the measurement data represents the Gaussian distribution, and the variance of measurement error increases in proportion to distance. This paper set a goal to analyze the characteristics of an infrared range finder and to correct the non-linear bias errors. The corrected infrared range finder can be utilized as an effective alternative to other sensors in indoor environment.

1 Introduction

A mobile robot collects information about its environment through external sensors. This is combined with the information provided by internal sensors and both of them are utilized to do navigation tasks. External sensors used in the mobile robot are ultrasonic, infrared, and laser sensors, vision cameras, and others. Each of them provides readings with a degree of uncertainty depending on the sensor characteristics.

Many techniques have been studied in the process of integrating data from different sensors[2]. These methods translate the different sensory inputs into reliable estimates that can be used by other navigation subsystems. Luo[3] shows the advantages gained through the use of multi-sensory information as a combination of four aspects: redundancy, complementariness, timeliness and cost of information.

Among External sensors, ultrasonic sensors have been used mainly to recognize environment[1], because the sensors have the advantages of the low cost and the possibility of real time measurement. Sonar sensors can measure distances up to nine meters[11], on the other hand, short distances are very imprecise and they have many problems with multiple reflections and wide beam width[3]. The two measurement
characteristics to be improved are range accuracy and angular resolution. One is to use optimal filtering to better determine the reception moment of the ultrasonic wave. Also, by utilizing an ultrasonic linear array, it verifies the improvement of using the ultrasonic sensors[12]. The improvements are, however, often attained to the detriment of cost effectiveness and simplicity.

Some infrared sensors can measure up to eighty centimeters with less uncertainty than sonar. Also an infrared range finder can detect all objects in front of the mobile robot after sensing. Therefore, it will be substituted for ultrasonic sensors or used more than sonar sensors as a distance recognition sensor for the mobile robot. Benet [9] proposed the way to acquire more accurate angles and distances with the consideration of the reflectance characteristics of the object surface. But the method limited the measurement confidence interval by 1 metres, and did not consider nonlinearities.

This paper aims at analyzing the characteristics of the infrared range finder by using relatively low cost IR scanner, and correcting the irregular effective elements by applying the infrared range finder to the measurement distance sensor. When working with neural networks, a key point is data gathering. In Section 2, we present the models of the sensors, a description of the data gathering process, and a characteristic analysis of the measurement data. In Section 3, we describe the neural networks we used, and the training procedure. In Section 4, we show the conducting experiments and some results. Finally, in Section 5, we present some conclusions.

2 The Characteristics of Infrared Range Finder Sensor

2.1 Structure and Specification of Infrared Range Finder Sensor

In this research, the PBS Series of Hokuyo Company is utilized as the infrared range finder. As shown in Fig. 1, the PBS sensor has a detector on the bottom and an emitter on the top. When the step motor placed the two reflective mirrors rotating, the measurement direction is determined. Scanning angle (Detection area) is 180 degrees. Operation principle is that the semicircular field is scanned by LED (lambda=880nm) and the coordinates are calculated by measuring the distance to the object and its step angle and then it detects obstacle in setting area. The module can measure from 10 centimeters up to 300 centimeters with accuracy and resolution depending on the distance. (Fig. 1 (b))
Table 1. Specification of the PBS Series

<table>
<thead>
<tr>
<th>Item</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Source</td>
<td>24VDC (allowed range 18 to 30VDC including ripple)</td>
</tr>
<tr>
<td>Current Consumption</td>
<td>250mA or less</td>
</tr>
<tr>
<td>Response Time</td>
<td>180ms or less (scanning speed 1 rev./100ms)</td>
</tr>
<tr>
<td>Scanning Angle</td>
<td>180°</td>
</tr>
<tr>
<td>Interface</td>
<td>RS-232C</td>
</tr>
</tbody>
</table>

There are three fundamental kinds of errors regarding the infrared sensors:

- Object color/reflectivity. Since the light reflectivity varies with color, the darker the object, the further it appears. The accuracy degrades quickly with the distance. The object may even be undetected.
- Global illumination. As a regular illumination contains light in the infrared band, the brighter the light, the further the object appears.
- Quantization error. This sensor converts the measurement up to 8 bits. This conversion is not linear in the full range, and therefore, the further the object, the less accurate is the reading.

2.2 The Characteristic Analysis of Infrared Range Finder

For the characteristic analysis of the PBS Series, the robotics platform used the mobile robot with a diameter of 387 millimeters. It has two differentially steered wheels, two caster wheels, and 12 pairs of sonar sensors, symmetrically and radially oriented at the intervals of 30 degrees, and finally, the PBS Series sensor is placed in front of the mobile robot.

The data acquisition procedure is as follows. A flat board in the front of the mobile robot is established. The mobile robot gathers the distance data of 200 samples at the intervals of 10cm while moving to the object from 300cm to 10cm. This data set has been used for neural network training.
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As shown in Fig. 3, the output of the PBS sensor represents non-linear bias value. Due to this nonlinearity, we have trained the sensor using neural networks.

Statistical analysis was carried out to analyze more accurately for the characteristics of the infrared range finder with the measurement data. After calculating the average and the standard deviation of samples gained at each measurement distance 50cm, 100cm, 200cm, and 300cm, the probability density function based on these estimation values is defined. Fig. 4 illuminates the probability density function with the Gaussian distribution on the measurement data.

The two characteristics of the infrared range finder sensor are summarized through these analyses. First, the samples show the Gaussian distribution. And the variance of measurement error increases in proportion to distance. Second, the measurement data represent the non-linear bias error in comparison to the real distance.

![Image of the PBS Series built in front of the mobile robot](image)

**Fig. 2.** The PBS Series built in front of the mobile robot

![Graph showing distance measurement](image)

**Fig. 3.** Result of distance measurement with the PBS Series. Where X axis is the actual distance between a mobile robot and an object, and Y axis is the measurement distance between them

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For utilizing the sensor for distance estimation and map building, appropriate signal processing algorithm is required to reduce the irregular elements. Statistical approach is able to reduce slightly of the source of error in distance estimation. Non-linear bias error, however, can not be fundamentally eliminated with that approach. Then, this paper set a goal to correct non-linear bias error.

3 The Correction of the Non Linear Bias Error using Neural Network

Neural networks are universal function approximators. They represent a new computing paradigm based on the parallel architecture of the brain. Neural networks are also known to be capable of providing a great capability of corrections at the present non-linear bias errors. For correction process in these kinds of errors, neural network must satisfy the real-timeliness of the system through minimizing the computing time in the real correction procedure. In this research, although the learning time took a long time, a response time applied to the system had to be quickly done, and neural network has been adopted.

This paper uses the MLP (Multi Layered Perceptron) network trained by using the Levenberg-Marquardt (LM) algorithm to correct error. The achievement performance
of the MLP network will highly depend on the structure of the network and training algorithm. Then, the LM algorithm has been selected to train the network. It has been shown that the algorithm has much better learning rate than the famous back propagation algorithm[8]. The LM algorithm is an approximation of the Gaussian-Newton technique, which generally provides much faster learning rate than back propagation that is based on the steepest decent technique.

Fig. 5 shows the structure and the training mechanism of neural network applied. A MLP is composed of a layered arrangement of neurons in which each neuron of a given layer feeds all the neurons of the next layer; that is, the network is formed by one input layer, two hidden layers, and one output layer. The first layer contains one input node, which is usually-connected to the hidden neurons. Each of two hidden layers and an output layer contains a bias. A neural network with two hidden layers was developed to achieve the desired accuracy in the modelization. The modelization capabilities of this network come from the hidden layer where a non-linear mapping of the input set is carried out. Thus, each neuron of these layers implements a non-linear transformation of its inputs.

Fig. 5. Structure and the training mechanism of neural network applied. (a) Structure of neural network, (b) Mechanism of neural network

Both hidden and output nodes have activation function and the function can be different. Hyperbolic tangent sigmoid is used for hidden nodes and identity function is applied for output nodes (Eq. (1), Eq. (2)).
The output combined with each activation functions is shown as followings.

\[ y_m = z_3 = f^3(f^2(f^1(xW_1^T + b_1)W_2^T + b_2)W_3^T + b_3) \]  

The input data of neural network is gathered with the same method in Section 2. A mean value of measurement data in each distance is used for the input data (Range data). Target range data is the real distance between the sensor and the object.

For training neural network, the LM algorithm that is efficient for solving the non-linear problems is used. Learning rate is 0.01. If the RMS error that is the difference of the output value from target value is under \(5 \times 10^{-5}\), the learning comes to an end. The training comes to a goal at 254 times.

### 4 Experimental Result

The results for the model proposed have been obtained within a MLP with architecture \((1 \times 6 \times 2 \times 1)\). Interconnection weights as the training completed is shown in (Eq. (4)).

\[
W_1 = \begin{bmatrix}
-4.795 \\
-5.292 \\
-1.956 \\
3.411 \\
-3.338 \\
-4.476
\end{bmatrix}, \quad b_1 = \begin{bmatrix}
17.392 \\
15.764 \\
5.585 \\
-3.8336 \\
1.465 \\
-1.081
\end{bmatrix}
\]

\[
W_2 = \begin{bmatrix}
1.170 & 0.818 \\
2.528 & -0.374 \\
-0.539 & -1.400 \\
-1.173 & -3.585 \\
-0.811 & -1.105 \\
-0.335 & -1.495
\end{bmatrix}, \quad b_2 = \begin{bmatrix}
-4.994 \\
-1.722
\end{bmatrix}
\]

\[
W_3 = \begin{bmatrix}
-3.675 \\
-1.495
\end{bmatrix}, \quad b_3 = \begin{bmatrix}
-0.836
\end{bmatrix}
\]
With the interconnection weights, we gained the measurement distance of the PBS Series sensor. Fig. 6 shows the results.

![Graph showing the result of correction using neural network](image)

**Fig. 6.** Result of correction using neural network

The results have been obviously better. It can be seen that the measurement distance is linearly yielded. Also, the standard normal distribution of each measurement distance (50cm, 100cm, 200cm, and 300cm) represents that the center points of measurement distance.

![Standard normal distribution graph](image)

**Fig. 7.** Standard normal distribution of each measurement distance (50cm, 100cm, 200cm, and 300cm). 300cm measurement data shows that it spreads more than the others

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Fig. 8. Measurement data of IR scanner before and after applying neural network in the experiment environment.

We construct the experiment environment of 600×450cm size for navigation of robot. Fig. 8 represents data of IR scanner before and after correction of non linear bias error. Measurement data after applying neural network show the correct distance between robot and obstacles. This show that corrected data can be utilized with distance value for obstacle detection, local map building, and localization of robot.

5 Conclusion

In this paper, we analyze the data characteristic of the infrared range finder, and set a goal of correcting the irregular elements in using the infrared range finder as the environment recognition system for mobile robot. From the research, the infrared range finder sensor has the increasing error with the distance of the objects gets farther away, and also has non-linear bias errors. By using the neural network proposed in this paper, we verify that non-linear bias errors are efficiently eliminated. Then, it can be utilized for global map building in the mobile robot navigation.

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References


Biography

▲ Name: Je-Goon Ryu

Address: 401-401, Bucheon Techno-Park, #193, Yakdae-Dong, Wonmi-Gu, Bucheon-City, Gyeonggi-Do, 420-734, Korea

Education & Work experience: He received the B.S. degree in Electronic Engineering from Inha University, Incheon, Korea, in 1999, and the M.S. degree in Electronic Engineering from Inha University, Incheon, Korea, in 2004, respectively. From 1999 to 2001, he was a junior researcher at R&D of MECA Information Communication Co. Ltd. Since 2004, he has been a junior researcher at Intelligence Healthcare system Research Center, Korea Polytechnic University.

Tel: +82-2-32-327-8838

E-mail: doctory@empal.com

Other Information: His main research interests are in the areas of service robot control, mobile healthcare system, robot vision, embedded system, and various industrial applications.
▲ Name: Hyeon Min Shim

Address: 253, Yonghyun-Dong, Nam-gu, Incheon, 402-751, Korea

Education & Work experience: He received the B.S. degree in Electronic Engineering from Inha University in 2001. He received the M.S. degree in Electronic Engineering from Inha University in 2003, respectively. He is currently working toward his Ph.D. at Inha University in the area of service robot system.

Tel: +82-32-868-4691
E-mail: elecage@paran.com

Other information: His main research interests are in the areas of service robot control system, motion planning, localization, map building and sensor systems.

▲ Name: Jae-Ho Shin

Address: 195-42, Anyang 7-dong, Manan-gu, Anyang-si, Gyeonggi-do, Korea

Education & Work experience: He received the B.S. degree in Bio Medical Engineering from Inje University, Kimhae, Korea, in 1993. He received the M.S. degree and finished course of the Ph.D. degree in Electronics Engineering from School of Electronic Engineering from Inha University, Inchon, Korea, in 1995 and 1987, respectively. From 1993 to 1994, he was a researcher at Industrial Robot Lab. of Korea Atomic Energy Research Institute. From 1996 to 2002, he was a researcher at Medison Co., Ltd. Since 2002, he has been CEO of HisBDIC Co., Ltd.

Tel: +82-2-31-442-4499
E-mail: ceo@hubdic.com

Other information: His main research interests are in the areas of service robot control, hospital healthcare system, home healthcare products and various healthcare applications.

▲ Name: Eung-Hyuk Lee

Address: 2121, Jungwang-Dong, Shihung-City, Kyonggi-Do, 429-793, Korea

Education & Work experience: He received the B.S. degree in Electronics Engineering from Inha University, Inchon, Korea, in 1985, and the M.S. degree and the Ph.D. degree in Electronics Engineering from School of Electronic Engineering from Inha University, Inchon, Korea, in 1987 and 1987, respectively. From 1987 to 1992, he was a researcher at Industrial Robot Lab. of Daewoo Heavy Industry Co. Ltd. From 1993 to 2000, he was a assistive professor at Dept. of Computer Engineering in Konyang University. Since 2000, he has been with the Department of Electronics Engineering at Korea Polytechnic University.

Tel: +82-2-31-496-8267
E-mail: ehlee@kpu.ac.kr

Other information: His main research interests are in the areas of service robot control, mobile healthcare system, image processing and various industrial applications.
A Study on the Correction of Non-Linear Bias Error

Name: Seung-Hong Hong
Address: 253, Yonghyun-Dong, Nam-gu, Incheon, 402-751, Korea
Education & Work experience: He received the B.S. degree in Electronic Engineering from Inha University in 1963. He received the M.S. degree in Electronic Engineering from Inha University in 1966, and the Ph.D. degree at the School of Biomedical Engineering from Tokyo University, Japan in 1975, respectively. He was a director and chairman at the Institute of Electronic Engineer of Korea from 1981 to 1994. He was a director, vice chairman, and chairman at the IEEE Korea Section from 1983 to 1997. He has been with the Department of Electronics Engineering at Inha University.
Tel: +82-32-860-7412
E-mail: shhong@inha.ac.kr
Other information: His main research interests are in the areas of bio-signal processing, rehabilitation engineering, medical image processing.

Name: Pyung-Soo Kim
Address: 2121, Jungwang-Dong, Shihung-City, Kyonggi-Do, 429-793, Korea
Education & Work experience: He received the B.S. degree in Electrical Engineering from Inha University in 1994. He received the M.S. degree in Control and Instrumentation Engineering and the Ph.D. degree at the School of Electrical Engineering and Computer Science from Seoul National University in 1996 and 2001, respectively. From 2001 to 2005, he was a senior researcher at the Digital Media R&D Center of Samsung Electronics Co. Ltd. Since 2005, he has been with the Department of Electronics Engineering at Korea Polytechnic University.
Tel: +82-2-31-496-8413
E-mail: pskim@kpu.ac.kr
Other information: His main research interests are in the areas of system software solutions, wireless mobile networks, internet protocol design, statistical signal processing, and various industrial applications.