Comparison of DEAS and GA for Sensitivity Optimization in MEMS Gyroscope

Hyunhak Cho
Department of Interdisciplinary Cooperative Course: Robot
Pusan National University, Busan, Korea
e-mail: darkruby1004@pusan.ac.kr

Moonho Park, Jaeyong Kim, Sungshin Kim
Department of Electrical and Computer Engineering
Pusan National University, Busan, Korea
e-mail: 82akakak, arioner, sskim@pusan.ac.kr

Abstract—**This paper is research into how to optimize the sensitivity values of an installed gyroscope in the autonomous guided vehicle with a magnet-gyro guided system. A magnet-gyro guided system mostly uses a MEMS gyroscope, which is small-sized, uses little power, and costs little. However, the MEMS gyroscope needs a high sensitivity value for changing angular velocity in each environment, not only due to the necessity of an accurate sensitivity value for the measured angle value but also due to the difference between the measured angle and sensitivity value. The sensitivity value describes the specifications of the sensor, but the sensitivity value is influenced by the given environment or gradient. Therefore, the optimization process is required for the sensitivity value of the installed gyroscope in the environment. A number of optimization algorithms have been studied, but we chose the Dynamic Encoding Algorithm for Searches (DEAS) and the Genetic Algorithm (GA) to optimize the sensitivity value. We used an AGV with laser navigation for experiments in this paper. We did 5 experiments for each change of the rotation angle - 30, 40, 50, 60° - and compared the calculations of the sensitivity value of optimization through the DEAS and the GA. The experiment results confirm that the optimization sensitivity values of the DEAS contain less error than the optimization sensitivity value by the GA algorithm.**

Keywords - DEAS, GA, Gyroscope, AGV

I. INTRODUCTION

An Autonomous Guided Vehicle (AGV) is a large mobile robot that can load and unload freights to the appointed position within either a fixed or unfixed path. Because it does not require manpower, AGVs can reduce wages and fatal accidents. Localization and position estimations are examples that use AGV technology [1]-[3]. Localization is a categorized wire and wireless guide method. The wire-guided method is a means for an AGV with detection by an attached or laid guideline to the floor. This method is used for safety reasons, but requires installation and maintenance. The wireless guide method remedies the wire guide method's shortcomings. It induces an AGV through a laser or an attached landmark to the ceiling or surface of a wall instead of a floor guideline. The wireless guide method has the advantage of not requiring installation of a guideline by driving an imaginary guideline. A typical device that uses the wireless guide method is laser navigation. Laser navigation has a ±25*mm* localization accuracy. It is also easy to modify the driving line, and extend workspace. But this comes at the cost of a slow response speed of 250*ms*, a big error of localization at a high speed or rotation driving. The magnet-gyro guide method is a new method to gain the advantages from both the wire and wireless guide methods. This method can induce an AGV by the measured magnet field information through installed magnets in the floor. The measured angular velocity by a gyroscope when there is no magnet, when the magnet is detected, the position and the angle of an AGV revise by the information of the detected magnet [4][5]. This method does not require the trouble of installation and maintenance of the wire guided method, and resolves the high cost of the wireless-guided method. Accuracy of the gyroscope for a position estimation of the vehicle is of importance in the magnet-gyro guide method because it induces an AGV by the measured yaw angle by the gyroscope when driving the gap of magnets. Commercialized gyroscope with a high accuracy is restricted to the AGV, because of its big size and large power consumption. The gyroscope of a Micro Electro Mechanical System (MEMS) was used for AGV miniaturization and low power. However, the MEMS gyroscope has problems such as low bias safety, low accuracy through noises, and low performance of straightness in comparison to the commercialized gyroscope. Generally, to calculate the sensitivity value for the angular velocity of the MEMS gyroscope, the representative value of the sensor specification must be used. However, because the sensitivity value is influenced by the given environment or gradient, an optimization method is required for the sensitivity value of the installed gyroscope in the environment. The existing optimization methods that use differentiation are complicated and need many arithmetic operations. So calculating the optimized sensitivity value is very difficult. Dynamic Encoding Algorithm for Searches (DEAS) optimization algorithm fits a Micro Control Unit (MCU) with a limited performance because the DEAS algorithm searches a global optimization solution without differentiation. This paper makes a comparison between the DEAS and the Genetic Algorithm (GA) in order to make a performance evaluation of the DEAS optimization algorithm. This paper is organized as follows. Section 2 presents the measurement system for a MEMS gyroscope. Section 3 goes into details regarding DEAS and GA algorithms for the optimization sensitivity value of the MEMS gyroscope. Section 4 mentions the experiments conducted and the results. Lastly, Section 5 is the conclusion of this paper.

II. MEASUREMENT SYSTEM

A. *Experimental system*

To experiment using the proposed method, an axel-driven fork type AGV with a built-in laser navigation was used. Laser navigation can measure global location. It is installed on top of the AGV to protect disturbances, and measures global position by using reflectors.

 ISBN: 978-1-61208-352-0

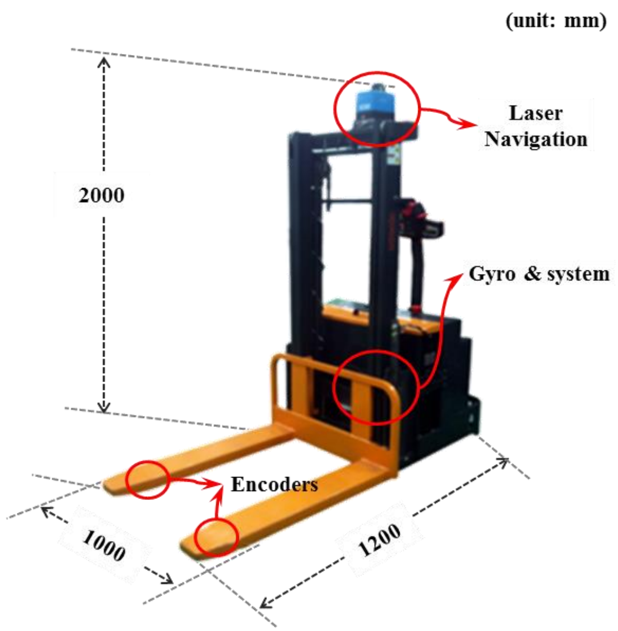

Figure 1. Forklift type AGV used in the experimet

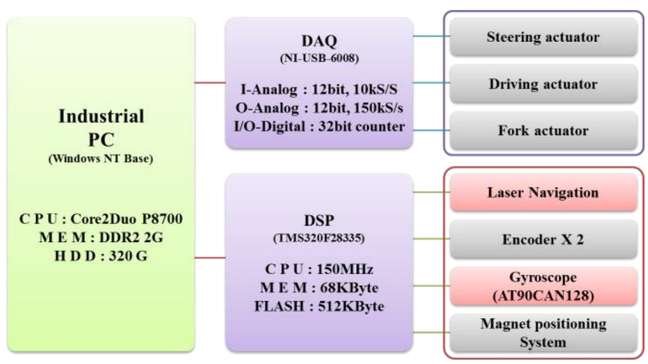

Figure 2. Hardware configuration of the AGV

The forklift-type AGV and the hardware configuration used in the experiment are shown in Figures 1 and 2, respectively. In Figure 2, industrial PC is used for rapid research and development. DAQ is used to control the driving parts of a manufactured forklift type. The position data of laser navigation is received through DSP every 500ms and the linear velocity of an encoder is received through DSP every 25ms. Transmission rates of MEMS gyroscope and magnet positioning system are 25ms and 100ms respectively. The data of the sensors is transferred from AVR to DSP. Encoders and gyroscope are used to measure a local position to compensate for the low response speed of laser navigation. The gathered data is sent to an industrial PC by DSP with RS-232 serial communication. Table 1 is the specification of installed sensors. The localization accuracy of laser navigation as a global positioning sensor depends on the number of recognized reflectors, and the distances between the sensor and reflectors. The sensor has a positioning accuracy of ±4mm and an angle accuracy of ±0.1°. MEMS gyroscope used in this experiment was designed by ADXRS613, AT90CAN-128 and 12bit ADC.

TABLE I. SPECIFICATION OF SENSORS

Sensor	Specification	
Laser Navigation (NAV200)	Supply voltage	24 V
	Positioning accuracy	±4 m～±25 mm
	Angular accuracy	±0.1 °
Gyroscope (ADXRS613)	Input voltage	5 V
	Range	±150 °/s
	Drift	±3 %
Magnet positioning system developed in our Lab.	Input voltage	5 V
	Sensitivity	10 mV/G
	Polarity	Bipolar (N/S)

B. *Calculation of angular velocity using gyroscope*

The output of MEMS gyroscope is influenced by temperature variation. The angular velocity value and the temperature value of the MEMS gyroscope are measured every 25ms. The output of gyroscope (O^+) depending on temperature is calculated using equation (1).

$$O^+ = O^- - ((2^{12}/2) - T) \times CA \qquad (1)$$

O^- and T is obtained through ADC data of each gyroscope. O^- is the raw data of the gyroscope and T is the temperature value. CA is the temperature constant and is set at 0.08. Equation (2) is the calculation method using the output value of a gyroscope.

$$\Delta\theta = (C - O^+) \times S \qquad (2)$$

C is the central output value of a gyroscope (0 ~ 4096: 2048). S is the sensitivity of the gyroscope, with an average value of 0.0125V/°/s in the datasheet. In this paper, the central value of the gyroscope is calculated by averaging 1000 data points obtained in the stop state of AGV. The ADC value of the gyroscope in a stop state is between 2034 and 2042. We used 2039 as the average output value. However, gyroscope has errors because the sensitivity of the installed environment of the sensor is not considered. To use MEMS gyroscope sensor as a navigation system, direct optimization is needed as a measurement system within a built-in MEMS gyroscope.

III. SENSITIVITY OPTIMIZATION

The sensitivity of gyroscope changes depends on the environment of the gyroscope's installed place and slope. To improve performance of the gyroscope, sensitivity optimization should be fulfilled in MCU with measured data in real time, because of the computation time and complex algorithm structure in existing optimization algorithms with stochastic or direct search, etc. Therefore the optimization algorithm for sensor needs a low computation for operating in real time. This paper proposes a simple and rapid method to optimize the sensitivity of the gyroscope through DEAS.

A. *Dynamic encoding algorithm for searches*

Existing optimization algorithms with derivative methods have high computation time. It is not suitable in real time.

Thus, sensitivity values should be directly optimized in MCU to consider the environment of a gyroscope. It is obvious that existing algorithms cannot be used if it has a high computation time. However, a DEAS algorithm can find both a local and global optimal solution of a cost function by using well-planned computer operations, which has a good operation time to performance [6][7]. The implementation of DEAS is simple. DEAS can also rapidly search optimal solutions on a low-spec computer because its source code is optimized by denoting a solution by binary code. It can solve nonlinear optimal problems as well as linear problems. DEAS is divided into two groups, local search plan and global search plan. Figure 5 represents the flow chart of the DEAS algorithm.

B. Local search strategy

DEAS is composed of Bisectional Search (BSS) and Unidirectional Search (UDS). Local search plan is optimized by using the features of a binary string. If 1 is pasted in LSB, the real number is increased, and if 0, it decreases. The BSS step is to paste 0 or 1 into the LSB of binary string and to determine the search direction. This step creates neighbor search locations at mutually opposite sides from the current search location. It can improve optimization and resolution about solution space. The USD step explores the local area until it finds the optimal value of the cost function. Figure 3 represents the flow chart of BSS. The BSS step tries to boost resolution by changing the length of the binary string and concentrates on finding the optimal solution. This step decides search locations near the current location. It initializes data except for the investigated optimal binary string in the previous section and pastes 0 and 1 at LSB of the binary string to create two neighbor search locations. The following equation (3) is applied to decode the binary string of generated neighbor search locations to be a value between 0 and 1, where b is the place value of the binary string and m is the length of the binary string. Optimal value is selected by comparing the calculated cost values. The binary string with optimal value is passed to the UDS step.

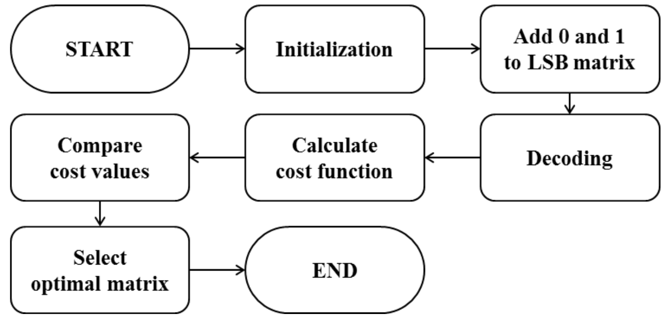

Figure 3. Bisectional search (BSS) of the DEAS

$$f_d(b_{m-1}b_{m-2}\cdots b_1 b_0) = \frac{1}{2^m-1}\sum_{i=0}^{m-1} b_i 2^i \quad (3)$$

A cost value of a selected neighbor location is calculated by adapting the decoded value in a cost function. USD has a global search feature to search a wide range of neighbor locations, which is decided by the unmodified state (to change length of binary string from BSS).

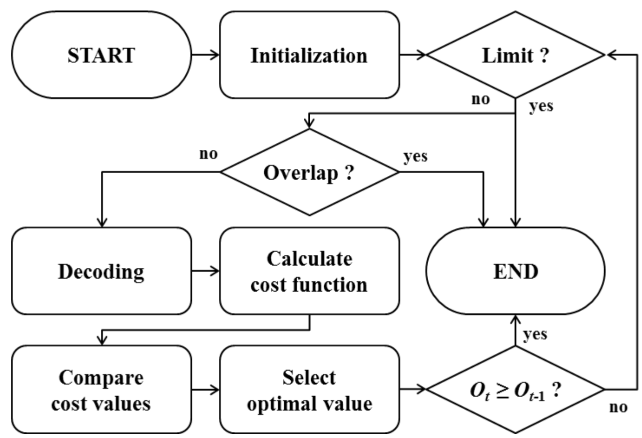

Figure 4. Unidirectional search (UDS) of the DEAS

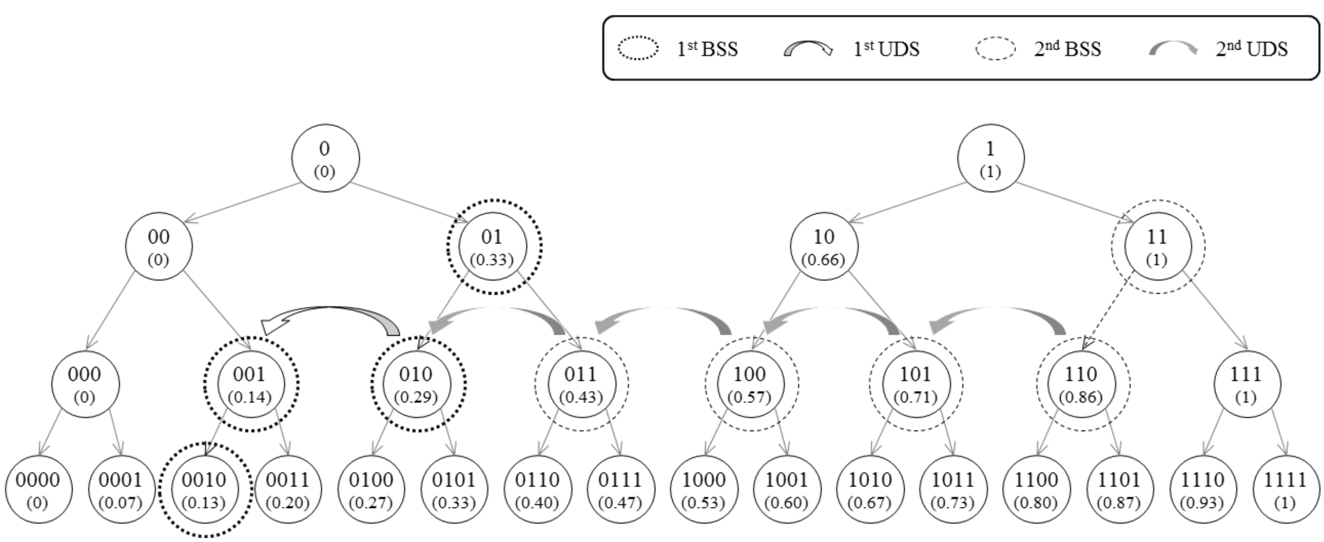

Figure 5. Flow chart of the DEAS algorithm

 ISBN: 978-1-61208-352-0

Also, the BSS step is just done just once but the UDS step is repetitively done until the value of the cost function is improved. Figure 4 represents the flow chart of the UDS step. In Figure 4, O_t is a currently-selected optimal solution, O_{t-1} is a previously selected optimal solution. The UDS step has two stages that are the Limit and Overlap stages. The Limit stage is a process to exclude the maximum and minimum binary strings in the UDS step. The Overlap stage is a process to exclude the previous optimal solution.

C. Global search strategy

The global search plan is performed to prevent being trapped in the local optimal solution by changing initial search locations. The global search plan can search a solution value by repetitively performing local optimal algorithms (change initial location). Figure 6 represents a flow chart of the global search plan. In Figure 6, t represents the number of performed global searches and n is the specified number of searches. In the local search plan, the searched location is stored as history to prevent searching previously searched locations.

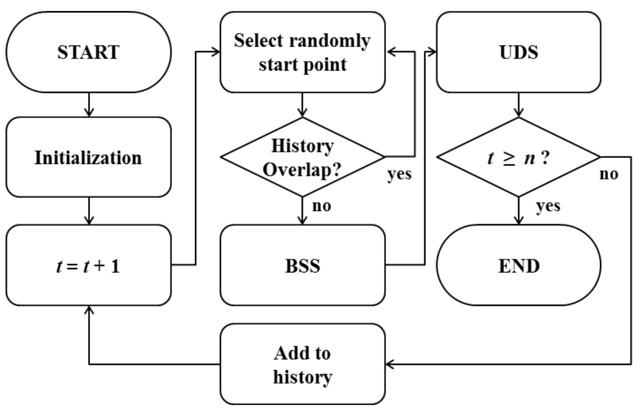

Figure 6. Global search strategy of the DEAS

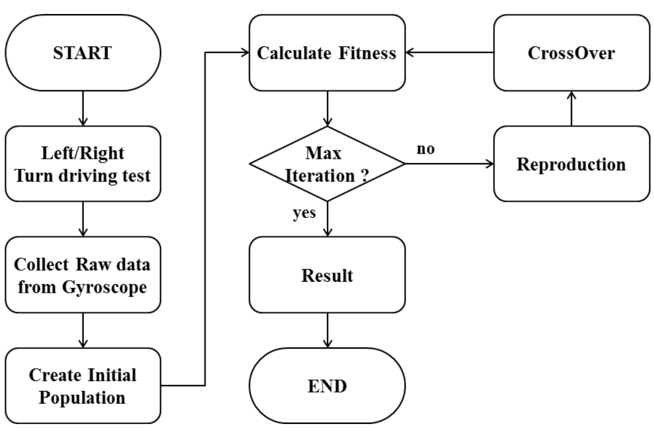

Figure 7. Sensitivitiy optimization using the GA

D. Genetic Algorithm

GA is one of the most famous algorithms in the field of optimization algorithms. Here it is used to evaluate the performance of the DEAS algorithm. GA, as stochastic search method, uses the natural phenomenon of genetic inheritance and competition for survival as its model. Figure 7 represents a flow chart of GA to optimize sensitivity of MEMS gyroscope. The repetition count number of GA is 100 in this paper. GA has crossover and reproduction operators. Two highly fitted chromosomes are selected in crossover. 50% of total chromosomes are selected as the next generation in reproduction.

E. Sensitivity value optimization of gyroscope

The proposed optimization algorithm of gyroscope's left and right sensitivities is searched through DEAS by using angle data of laser navigation after making AGV turn a full 360°. Figure 8 represents the flow chart of sensitivity optimization. *SR* is the sensitivity of right turning and *SL* sensitivity of left turning. *ESR* is a sensitivity error of right turning and *ESL* is a sensitivity of left turning. The following equation is a cost function to calculate *ESR* and *ESL*. Where O^+ is the calculated gyroscope's output through equation (4), N is the number of data.

$$f(x) = \sum_{i=0}^{N} \left(\frac{360 - x \times O^+}{N} \right) \tag{4}$$

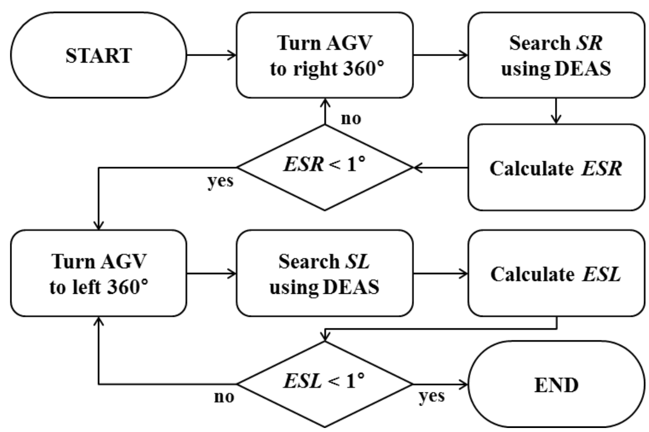

Figure 8. Sensitivity optimization using the DEAS

IV. EXPERIMENTS AND RESULTS

A. Experiment Environment

Pillar type reflectors are attached at the wall to measure the localization of laser navigation in an 840 x 2,010 *cm* experimental space. The laser navigation used in this paper is SICK's NAV200. The position can be measured with an accuracy of ±4 ~ 20 mm error. The experimental environment is Figure 9. The AGV is rotated 360° after the steer angle is fixed using laser navigation, and the raw data of the MEMS gyroscope is saved. The AGV is driven to turn left and right, each 2 times. The saved raw data of gyroscope is optimized using DEAS and GA in each turn direction. To evaluate the performance of the two algorithms, we compare the calculated error using the optimized sensitivity through each algorithm using the sensitivity of specification during the 360° turn.

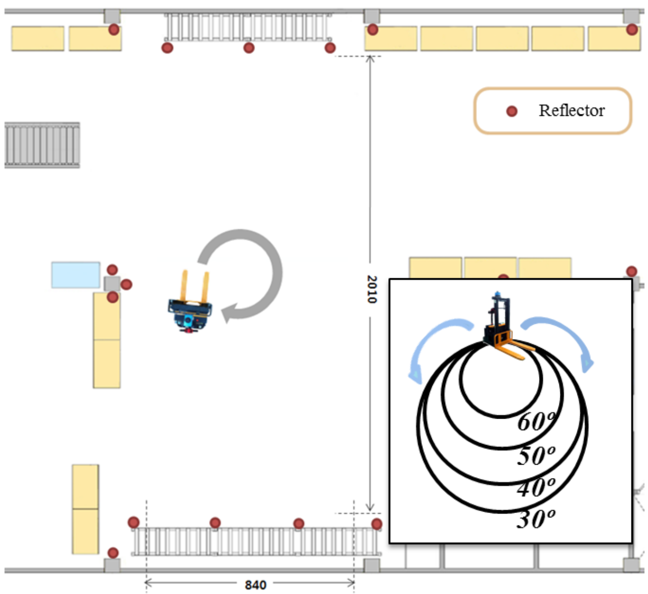

Figure 9. Experiment environment

TABLE II. RESULTS OF RIGHT TURN DRIVING TEST

Steering angle	Driving speed	Error (unit: degree)		
		DEAS 0.0250065	**GA 0.0250100**	**Specification 0.0312000**
30°	23cm/s	0.9130	1.1756	44.7037
	28cm/s	0.1366	0.3375	43.7647
	33cm/s	2.0005	1.7400	41.4367
	38cm/s	1.9141	1.6536	41.5336
	43cm/s	1.6253	1.8885	45.5025
	Average	1.3179	1.35904	43.38824
40°	23cm/s	6.3567	6.0994	36.5519
	28cm/s	7.6233	7.3669	35.1317
	33cm/s	1.2125	1.3007	44.7940
	38cm/s	1.2157	1.4785	45.0432
	43cm/s	2.3198	2.5834	46.2812
	Average	3.7456	3.7658	41.5604
50°	23cm/s	1.1268	1.0404	43.2863
	28cm/s	2.2025	1.9421	41.2102
	33cm/s	2.067	1.8609	41.3617
	38cm/s	2.6230	2.5375	42.2637
	43cm/s	0.7349	0.7930	44.1374
	Average	1.75084	1.6348	42.4518
60°	23cm/s	10.3118	10.5813	55.2430
	28cm/s	9.5866	9.8555	54.4297
	33cm/s	8.6028	8.8710	53.3266
	38cm/s	3.8603	4.1250	48.0086
	43cm/s	7.0361	7.3032	51.5698
	Average	7.8795	8.1472	52.5155
Total average		3.6734	3.7267	44.9790

B. 360° right turn driving test

Table 2 shows the angle error of the 360° rotation. The unit of sensitivity is V/°/25ms. The result of Table 2 is the average of 5 times.

The optimized sensitivity using DEAS on the right rotation was 0.0250065 V/°/25ms, and sensitivity using GA was 0.0250100 V/°/25ms. The results of error on 360° rotation are 3.4855°, 3.5347°, and 45.0002° in DEAS, GA, respectively.

TABLE III. RESULTS OF LEFT TURN DRIVING TEST

Steering angle	Driving speed	Error (unit: degree)		
		DEAS 0.0250021	**GA 0.0251250**	**Specification 0.0312000**
30°	23cm/s	1.3038	0.5964	44.3587
	28cm/s	1.6253	3.0241	45.5025
	33cm/s	1.9141	3.0223	41.5336
	38cm/s	2.0005	3.9514	41.4367
	43cm/s	0.1366	0.9397	43.7647
	Average	1.3960	2.3068	43.3192
40°	23cm/s	1.7027	2.3719	43.5772
	28cm/s	2.3198	3.6942	46.2812
	33cm/s	1.2157	0.5316	45.0432
	38cm/s	1.2125	0.4940	44.7940
	43cm/s	7.6233	1.4934	35.1317
	Average	2.8148	1.7170	42.9654
50°	23cm/s	1.1268	0.8255	43.2863
	28cm/s	2.2025	0.6864	41.2102
	33cm/s	2.0670	1.8685	41.3617
	38cm/s	2.6230	3.2094	42.2637
	43cm/s	0.7349	1.4426	44.1374
	Average	1.7508	1.6065	42.4519
60°	23cm/s	10.3118	17.8615	55.2430
	28cm/s	9.5866	12.9053	54.4297
	33cm/s	8.6028	11.9679	53.3266
	38cm/s	3.8603	10.8698	48.0086
	43cm/s	7.0361	9.3469	51.5698
	Average	7.8795	12.5903	52.5155
Total average		3.4603	4.5551	45.3130

C. 360° left turn driving test

The result of the right turn experiment in the same condition with left turn is as in the following table. As Table 3 shows, the sensitivity on the left turn using DEAS is 0.0250021V/°/25ms and the sensitivity using GA is 0.0251250V/°/25ms. The average errors on the right 360° turn driving are 3.4855°, 4.1265° on each algorithm. The average error using specification is 45.0002°. For left turn driving, less error occurred using sensitivity calculations than in using specification. This is because the sensitivity of specification does not consider the environment of the gyroscope such as tilt and electric noise, among others.

Figure 10 shows error using optimized sensitivity through each algorithm. As verified in Figure 10, the left part in the boxplot is the experiment result (angle error) of the

 ISBN: 978-1-61208-352-0

right turn driving test and the right part is the experiment result of the left turn driving. In the result, errors using DEAS and GA are lower than errors of specification values from the left/right turn-driving experiment. However, GA is not proper in MCU because it requires high computation to show good performance. DEAS is proper in MCU, which finds the optimal solution of cost function by only using well-planned operations.

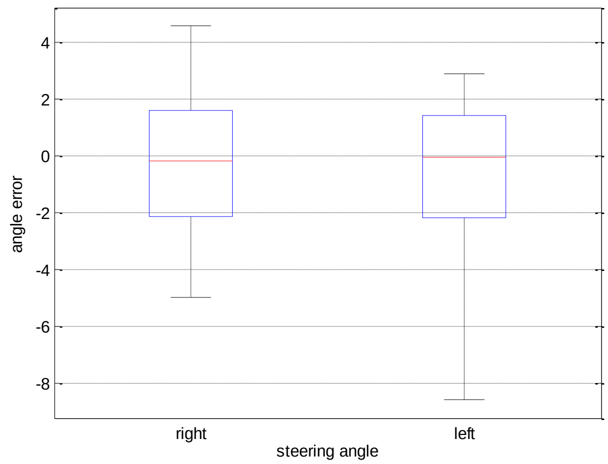

Figure 10. Boxplot of errors on right/left turn driving tests

V. CONCLUSION

In this paper, we implemented and compared performances using DEAS and GA, which are well known optimization methods. Sensitivity optimization of MEMS gyroscope is very important due to low angular velocity accuracy and a low straightness performance. Therefore, a sensitivity value of a gyroscope should be optimized from MCU to measure the data of a gyroscope. Because existing optimization methods have high computation and complex algorithms, it is difficult to apply in MCU. However, a well-planned DEAS algorithm is simple and has a lower computation time than the existing algorithm. Therefore, this paper suggests sensitivity optimization of a gyroscope through DEAS. To verify the performance of the proposed method, we compared the result of DEAS with the result of GA. As for experimental results, the average error using sensitivity of specification (in gyroscope datasheet) was 45.0002°, 45.0002° on turns right and left, respectively. The average error of sensitivity value through DEAS and GA from right turn driving respectively are 3.4855°, 3.5347°, and the result of left turn driving are 3.4855°, 4.1265° respectively. As calculated error using optimized sensitivity through DEAS and GA, average errors on right turn driving are 0.0250065°, 0.0250100° and on left turn driving is 0.0250021°, 0.0251250°. As the results show, the proposed method had a better performance than the result of specification. As part of future research, we plan to study what reduces drift and changes sensitivity in real-time with tile of AGV.

ACKNOWLEDGMENT

This research was supported by the MOTIE, KOREA under the Human Resources Development Program for SPENALO Research Center support program supervised by the NIPA (H1502-13-1001) and supported by a 2-Year Research Grant of Pusan National University.

REFERENCES

[1] M. P. Groover, “Automation, Production Systems and Computer Integrated Manufacturing”, sigma press, August, 2007.

[2] J. Ota, A. Shinozaki and H. Hashimoto, “Hybrid Design Methodology and Cost-Effectiveness Evaluation of AGV Transportation System,” Automation Science and Engineering, IEEE Transaction on, vol. 4, no. 3, July, 2007, pp. 360-372.

[3] J. Villagra and D. Herrero-Perez, “A Comparison of Control Techniques for Robust Docking Maneuvers of an AGV,” Control Systems Technology, IEEE Trans. on, vol. 20, no. 4, July, 2012, pp. 1116-1123.

[4] C. Y. Chan, “A System Review of Magnetic Sensing System for Ground Vehicle Control and Guidance,” California PATH Research Report, UCB-ITS-PRR-2002-20, May, 2002.

[5] Y. Pang, “Bipolar magnetic positioning system for automated guided vehicles,” Intelligent Vehicles Symposium 2008 IEEE, June, 2008, pp. 883-888.

[6] J. W. Kim and S. W. Kim, “Parameter identification of induction motors using dynamic encoding algorithm for searches,” IEEE Transaction on Energy Conversion, vol. 20, no. 1, March, 2005, pp. 16-24.

[7] J. W. Kim and S. W. Kim, “Numerical method for global optimization: dynamic encoding algorithm for searches,” IEE Proceeding Control Theory and Applications, vol. 151, no. 5, September, 2004z, pp. 661-668.

 ISBN: 978-1-61208-352-0