Self Localization of Mobile Robot Using Sonar Sensing and Map Building

Ji-Min Kim*, Ki-Seong Lee** and Tae-Won Jeong*

* Department of Electrical Engineering, Chungnam National University, Daejon, Korea
(Tel : +82-42-821-7602; E-mail: jiminik@daum.net)
**Hankook Tire Co. Ltd.
(E-mail: bionda@hanta.co.kr)

Abstract: A location estimate problem is critical issues for mobile robot. Because it is basic problem in practical use of the mobile robot which do what, or move where, or reach an aim. Already there are many technologies of robot localization (like GPS, vision, sonar sensor, etc) used on development. But the elevation of accurateness was brought the problem that must consider an increase of a hardware cost and addition electric power in each ways. There is the core in question to develop available and accurate sensing algorithm though it is economical. We used a ultrasonic sensor and was going to implement comparatively accurate localization though economical. Using a sensing data, we could make a grid map and estimate a position of a mobile robot. In this paper, to get a satisfactory answer about this problem using a ultrasonic sensor.

Keywords: localization, mobile robot, sonar, map building

1. INTRODUCTION

Recently, Study on service robot which can be easily utilized in a mass daily life is progressed actively throughout the world. More than many industrial robots which substituted for repetition work of a person or work to have been hard, service robot as a cleaning robot, a rehabilitative robot, an operation robot, etc raised quality of a human life. It is the mobile robot which mostly used a wheel of this service robot. So, a study about mobile robot must be preceded. But in order to maximize a use rate of this mobile robot, a problem to estimate a accurate location of moving robot more first than anything must be solved. We can consider the way that let it move on a schedule orbit like an industrial robots for accurate control of location. However, it is hard to install a trajectory for a robot which helps domestic activities such as delivery, cleaning in a daily life. So, each robot must be having a function of estimate location by itself, and to plan a course.

A lot of technology that used GPS or a vision sensor, ultrasonic sensor, laser range finder in order to get accurate information of location of a robot is already used. But, a disadvantage like matters connected with a change of illumination, a cost, interface, a response speed has each sensors. Then, Robot must have got much information about environment of robot and use an economical and widely used sensor for a successful, effective position estimate. It is asked to build a map about a robot surrounding environment for a position grasp of a robot additionally and to get an obstacle or surrounding environment information.

This paper presents a method for localization and map construction of a mobile robot using data from a sonar-based range sensor. No prior knowledge of the environment is assumed. The map is constructed autonomously by the robot.

And this paper is going to suggest position estimate algorithm though it is economical, offer a lot of information and simple interface using a widely used ultrasonic sensor.

2. THE ENVIRONMENT RECOGNITION THAT USED ULTRASONIC SENSOR

2.1 Map building which considered a characteristic of ultrasonic sensor

A ultrasonic sensor transmits and receives a beam of conic form in a Figure 1. in a characteristic. form in a Figure 1. in a characteristic. It is hard to get correct position information from an ultrasonic sensor by this characteristic directly, and a sensor can only know what only coordinate information provides. To revise the incorrectness nature of a ultrasonic sensor and to get location information as obstacles, wall, etc we can use a grid map. And it is asked to consider the restriction that must consider a characteristic to have been based on an angle of reflection of a ultrasonic sensor, an atmospheric influence, sensitivity about noise, and to apply to a position estimate problem.

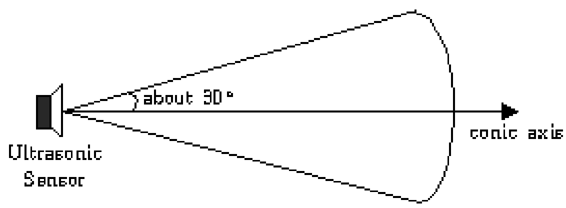

Figure 1. A conic characteristic of ultrasonic sensor

2.2 Grid Map

To create a useful local map, the algorithm requires range measurements in a number of different directions. Such measurements are readily obtained by sweeping the sensor. The robot used in this paper features a sonar sensor that is mounted on a servo, so a 180-degree sweep is possible. More information about this localization algorithm can be found in reference. There is the way that used a grid map and a topological map in the method of map building that used a ultrasonic sensor. The grid map shown in Figure 2. is the method which show and express surrounding environment to the determined size and it shows the surrounding environmental information by the way which the obstacle exist in each grid or not generally. The grid map method has the advantages which express the relatively precise geometrical information of environment. However, it also the disadvantage which much memory is needed to get all obstacle information of surrounding environment and the accuracy of the map is not good when the environment varies. This kind of grid map has a role to revise the uncertainty of sensors through the more precise modeling relatively using the probability grid. Figure 3. shows the expressing way of information by making the probability to numerical values in Carnegie Mellon University.[3] As mentioned above, a 2-dimensional grid is used to provide a map of the robot's environment. The grid map consists of a matrix of cells, each containing an occupancy value and a certainty value. These values are used by the occupancy and localization algorithms respectively.

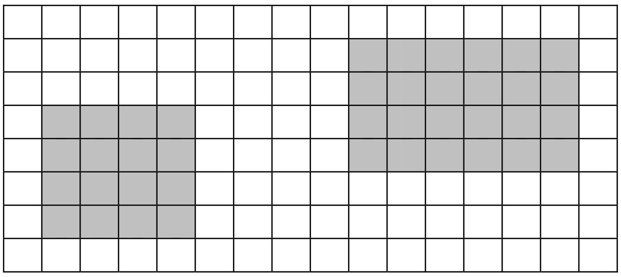

Figure 2. A form of Grid Map

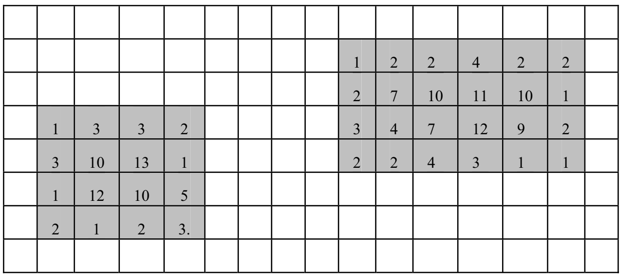

Figure 3. A Certainty Grid Method

2.3 Topological Maps

On the other hand, the topological map shown in Figure 4. can be expressed simply using some nodes and their connections. It has the advantage of expressing the exact information of surrounding environment without absolute basis coordinate. However, whenever the measurement distance and space are increased in ultrasonic sensors, the error of the sensor is increased and it is difficult to construct the map of large scale. Also, it is hard to apply on expressing the obstacles and positions with complicate shape.

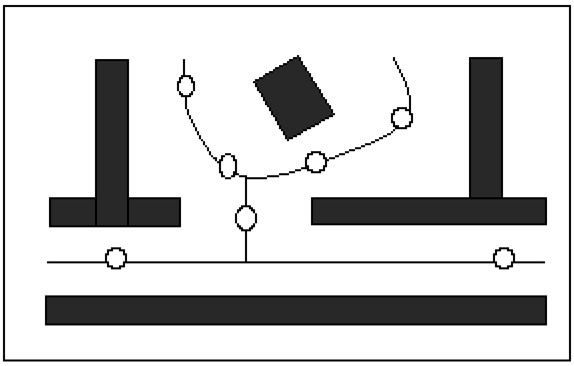

Figure 4. Topological Map Method

3. SELF LOCALIZATION SYSTEM USING THE ULTRASONIC SENSORS

Figure 5 shows the self localization system which is suggested in this paper. It is assumed that ultrasonic transducer is localized on robot and it can rotate when the robot moves. The rotating angle is determined to 90 degree to get the forward environment informations with considering directivity of ultrasonic sensors. Also the rotational speed of the sensors and proceeding speed of robot are determined by receiving and processing of transmitted signal.

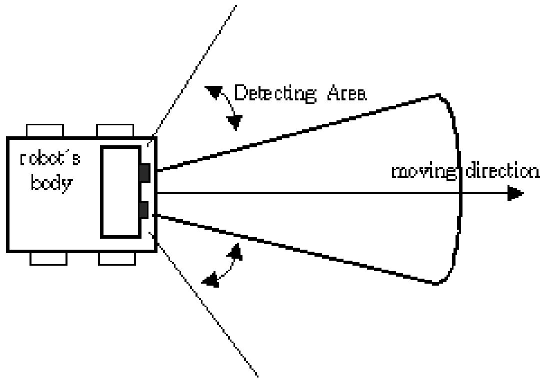

Figure 5. Self-localization system using ultrasonic sensor

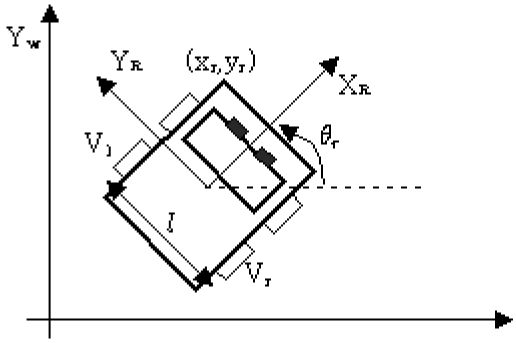

Figure 6. A mobile robot model

3.1 The uncertainty of location estimation

Although it is known that the precise initial position of the mobile robot, the slip of robot and sensor measurement errors are increased with time. To model these, the state of mobile robot is expressed as the vector $[xr; yr; \Theta r]^T$ with position and direction on two dimensional plane as shown in Figure 6. And the small position change and direction change of two wheel drive robot are given like by [4]

$$X_r(k+1) = X_r(k) + T\frac{u_r(k)+u_l(k)}{2}\cos\theta_r(k)$$

$$Y_r(k+1) = Y_r(k) + T\frac{u_r(k)+u_l(k)}{2}\sin\theta_r(k)$$

$$\theta_r(k+1) = \theta_r(k) + T\frac{u_r(k)-u_l(k)}{l}$$

where *ur* and *ui* are the progressing velocity of righ and left wheel respectively, *l* is the distance between two wheels, and *T* is the sampling time.

ur and *ui* are values that it reads a fan shape speed price of measured right and left motor, and it is, and is calculated with encoder displacement stuck to to a mobile robot. This causes an estimate error of a mobile robot's state vector. It works as below if I express *ur* and *ui* with a state equation form by a system input with variable state with situation *x* of a robot.[4]

$$x(k+1) = f(x(k), u(k) + v(k)) + w(k)$$

where,

$$x(k) = [x_r(k) y_r(k) \theta_r(k)]^T, \; u(k) = [u_r(k) u_l(k)]^T$$

v(k) is A speed error of a wheel, *w(k)* is other errors. Therefore, a value of a location estimate of a robot and a covariance line of an error are as follows.

$$\hat{x}(k+1) = f(\hat{x}(k), u(k))$$

$$P(k+1) = A(k)P(k)A(k)^T + F(k)V(k)F(k)^T + W(k)$$

where,

$$A(k) = \begin{bmatrix} 1 & 0 & -T\dfrac{u_r(k)+u_l(k)}{2}\sin\hat{\theta}_r(k) \\ 0 & 1 & T\dfrac{u_r(k)+u_l(k)}{2}\cos\hat{\theta}_r(k) \\ 0 & 0 & 1 \end{bmatrix}$$

$$F(k) = \begin{bmatrix} \dfrac{1}{2}T\cos\hat{\theta}_r(k) & \dfrac{1}{2}T\cos\hat{\theta}_r(k) \\ \dfrac{1}{2}T\sin\hat{\theta}_r(k) & \dfrac{1}{2}T\cos\hat{\theta}_r(k) \\ \dfrac{T}{1} & -\dfrac{T}{1} \end{bmatrix}$$

This error covariance formula shows uncertainty of a robot situation estimate. It could observe an uncertainty degree geometrically using a uncertainty ellipsoid than analyzing covariance culumn elements directly.[5] As a robot moves, and an error is accumulated and can see uncertainty grow larger.

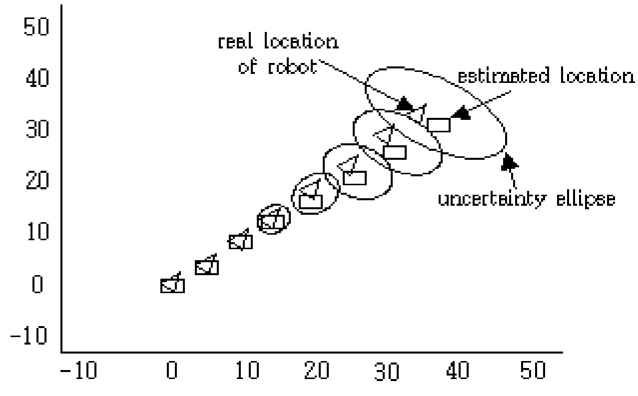

Figure 7. Uncertainty ellipse of a estimation with time

3.2 The self- localization that used Extended Kalman Filter

Based on a sonar data map, estimate a location of robot of the moment. However, There is a unreliable component is existing in location estimation by low sensitivities of sensors, motor oscillation and outside conditions. So, uncertainty is still existing in a location estimate. Used a Kalman Filter that estimates state steadfastly, revised errors in a location estimation. Then estimate robot's own location exactly by the compensated data.

A system has a trouble in a correct modeling by a noise and unlinearity in a lot of robots and sensor applications. The surrounding environment coordinates that calculated a situation estimate of a mobile robot for a standard show you a difference with it being observed the real. In this way a robot uses Kalman Filter in order to assume real values of a signal if a noise is included in a measured signal.[6] Relationship between a measurement signal and coordinates of a mobile robot is unlinear in a system to propose it in this paper. So, It must be apply a for a unlinear system.

State vector *r* of a mobile robot consists of location (x,y) and direction 3 of the 2-Dimension as explained at the front. A state equation is calculated by a point model to have been well-known as below.

Where, $r = [x, y, \theta]^T$ is state vector, $u = [T, \Delta\theta]^T$ is control input, and $w_k = [w_{1,k}, w_{2,k}, w_{3,k}]^T$ is a Gaussian noise that has average, 0, covariance, Q . Or $w_k \sim N(0, Q)$ and *k* means time state.

$$r_{k+1} = f(r_k, u_k, w_k) = \begin{bmatrix} x_k + T_k\cos\theta_k + w_{1,k} \\ y_k + T_k\sin\theta_k + w_{2,k} \\ \theta_k + \Delta\theta_k + w_{3,k} \end{bmatrix}$$

As mentioned above, in state equation and observe equation, Extended Kalman Filter algorithm can describe to assume a state vector of a mobile robot as below.

$$\hat{r}_{k+1} = f(\hat{r}_k, u_k, 0)$$

$$P_{k+1} = A_k P_k A_k^{\,T} + Q$$

$$K_k = P_k^- H_k^{\,T}(H_k P_k H_k^{\,T} + G)$$

$$\hat{r}_k = \hat{r}_k^{\,-} + K_k(z_k - h(\hat{r}_k^{\,-}, 0))$$

$$P_k = (I - K_k H_k)P_k^-$$

3.3 Localizaton Algorithm of mobile robot

The localization algorithm is the key of the positioning application. It requires as input: the global map with the occupied cells, a range sensor sweep(consisting of an array of range vectors) and optionally an estimated location (from the dead reckoning algorithm). It the estimated location is not available localization will be performed in the complete map; otherwise the localization will be restricted around the estimated location(within a circle with the estimated location at its center).

Localization is performed for a simple map with only three occupied cells and two range vectors. The algorithm relies on the assumption that each range vector ends at an occupied cell and that the path between the origin of the vector and the occupied cell is unobstructed. The procedure is quite simple, apply the end of each vector to an occupied cell, if the vector is unobstructed then increase the certainty value(or vote) of the cell at the start of the vector. This procedure is repeated for all occupied cells and range vectors. Selecting the best location is not always as straight forward as simply choosing the cell with the highest certainty value. In many cases more than one cell will have the maximum certainty value. In real world environments the votes will also be distributed around the present location due to the noise in the sensor readings. The localization algorithm must take these in to account before choosing the best location. To increase the accuracy of the localization algorithm is to localize incrementally. To do this more than on range sensor sweep is used to perform localization. Each Sweep is done from a separate location so that a more complete view of the environment can be seen. This process can be thought as building a local map and then comparing this map with the global map. Normally a single sweep will be used to build the local map; but if more sweeps are added, the localization process will be more accurate. In order to build the local map, the estimated location from the dead reckoning algorithm is required (since localization cannot be performed in the local map). It was found that best results are observed when between two and four sweeps are used to build the local map. If more are used, the map will be distorted due to the positioning errors of the dead reckoning algorithm. This will in turn lead to errors in the localization process.

4. EXPERIMENTATION AND CONSIDERATION ABOUT SYSTEM PERFORMANCE

4.1 Experiment Process

The algorithm described in the previous section have been implemented and tested in an indoor environment using a small mobile robot equipped with an ultrasonic range sensor. In the following sections the robot used in the experiments will be first briefly described, finally the results obtained from a run in the simulator and in a real world environment will be presented. It is going to verify the self- position estimate algorithm that used a system and the Extended Kalman Filter which proposed in above. As for the approximate map building is possible on an indication with a form to be circular in corner parts because were detected to be continuously strong with a shape of arc. In actual robot, map construction was hard to make a accurate map. The positioning accuracy varies, depending on the location and the errors in the range readings.

Robot loaded ultrasonic module that transmit and receive as mentioned above. While robot moves, assumed robot's course to an axis. Equipped module does not move upper and lower direction. A revolution is possible in right and left each 45°. In order ot take the processor intensive tasks off the on board microcontroller a RF link is required. The Radiometrix BIM-433-F transceivers are used in this robot. The robot is responsible of all low level control tasks, such as motor and sensor control. All high level control tasks(positioning and map building) are running in a remote PC. The ultrasonic sensor used the SRF04 sensor module that was a British Devantech gratitude model. It is the maximum detection range 3m, frequency 40kHz and operates in 0 degrees - 40 degrees.

The experimentation was carried indoors out. a space of 2meter size was composed with a width, and a robot moved. It was composed with size of 12cm, high 10cm with a width 18cm, lease the size of a robot. The robot set up a course as a standard with a specific point. Each gratings did it so that they divided it by size of 5cm with a width, a lease, and environment information was composed. The following table 1. that compared an estimate with an actual value of environment information to have shown at coordinates.

	x_r	x_e	y_r	y_e
1	2.50	3.02	10.00	10.57
2	45.00	46.21	42.50	45.41
3	22.50	23.45	75.00	70.97
4	107.50	105.13	82.50	84.21
5	185.00	186.11	147.50	148.46
6	192.50	194.41	175.00	176.44
7	180.00	183.01	190.00	193.21

Table 1. A Comparison of real value and an estimate

Value of Table 1. expressed with the following Figure8-9.

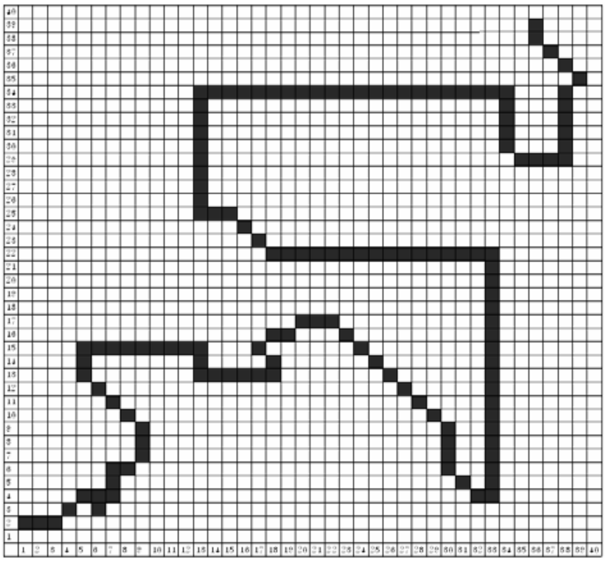

Figure 8. Real Value of Robot's Position

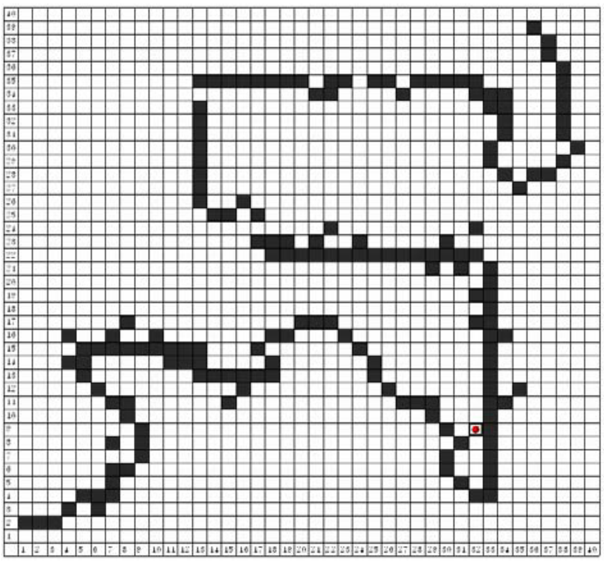

Figure 9. Estimated Value of Robot's Position

The positioning accuracy varies, depending on the location and the errors in the range readings. Typical Values are in the range of 10cm, some times errors as high as 20cm were observed due to errors in the range readings. Fortunately this doesn't happen very often and even when it does, a second sweep from a slightly different position will most likely produce better results. Range errors due to higher order reflections of the ultrasonic pulse can be clearly seen all over the map but overall they didn't have a major impact on the structure of he map.

5. CONCLUSION

It is proposed a system of a form a ultrasonic generator turned in order to know a position of a mobile robot and direction information in this paper, and to receive. Self localization system in this paper used a ultrasonic sensor and was going to implement comparatively accurate localization though economical. Using a sensing data, we can make a grid map and estimate a position of a robot. A problem was able to observe that there was it in order to use a position estimate system in real time estimation. And by the results of experiment, we able to know the accuracy of a position estimate in proportion to quantities of detected data. It is an example that accuracy drops because a detected data was little in some places(like the corner). Supplement a characteristic of a ultrasonic sensor is required in order to supplementing accuracy and speediness In future study.

REFERENCES

[1] Jose A. Castellanos and Juan D. Tardos, *Mobile robot localization and Map building : A Multisensor Fusion Approach,* Kluwer Academic Publishers, 2000

[2] Gregory Dudek and Michael Jenkin, *Computational principles of mobile robotics,* Cambridge University Press, 2000

[3] A Elfes, "Occupancy grids : A Probablistic Framework for Robot Perception and Navigation", *PhD thesis*, Department of Electrical and Computer Engineering, Carnegie Mellon University, 1989

[4] K. Komoriya, E. Oyama and K. Tani, "Planning of landmark measurement for the navigation of a mobile robot", *Proceeding of the IEEE/RSJ International Conference on Intelligent Robots and Systems,* July 7-10, 1992

[5] Y. Nakamura, *Advanced Robotics : Redundancy and Optimization,* Addison-Wesley, 1991

[6] R. Brown and P. Hwang, *Introduction to random signals and applied kalman filtering,* John Wiley and Sons, 1992

[7] J. Leonard and Durrant-Whyte, *Directed Sonar sensing for mobile robot navigation,* Kluwer Academic Publishers, 1992

[8] Soo-Yeong Yi and Jae-Ho Jin, "Self-localization of mobile robot using global ultrasonic sensor system", *Journal of Control, Automation, and Systems Engineering,* Vol.9, No.2, February, 2003

[9] J.L Crowley, "World Modeling and Position Estimation for a Mobile Robot Using Ultrasonic Ranging", *IEEE International conf. on Robotics and Automation,* pp.674-680,1989

[10] A Curz, "Constructing Maps for Mobile Robot Navigation based on Ultrasonic Range Data" *IEEE Trans. on System, Man Cybernetics part B : Cybernetics*, vol.26, pp. 233-242, Apr.1996

[11] W.D. Rencken, "Concurrent Localization and Map Building for Mobile Robots Using Ultrasonic Sensors", *Procs. IEEE/RSJ International conf. on Intelligent Robot and System*, pp 2192-2197, July,1997

[12] L. Kleeman and R. Kuc, "An Optimal Sonar Array for Target ;Pca;ozaotpm amd Classification", *Procs. 1994 IEEE International Conf. on Robotics Automation*, Dan Diego, CA, pp.3130-3135, May, 1994

[13] F. J. Zhao, H.J. Guo and K. Abe, "A Mobile Robot Localization Using Ultrasonic Sensors in Indoor Environment", *IEEE International Workshop on Robot and Human Communication*, pp.52-57,1997

[14] M. Drumheller, "Mobile Robot Localization Using Sonar", *IEEE Trans. on Pattern Analysis Machine Intelligence*, vol. PAMI-9, pp. 325-332, Mar. 1987