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An effective localization and navigation method based on sensor fusion for mobile robot moving in unknown indoor environment

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Abstract: Odometry is simple and fast method to estimate the position and orientation of the moving robot. However, there are some errors in detecting the correct position. Moreover, the errors continuously accumulate. To cope with this problems, Absolute position correction is necessary, and they are usually based on external measurements such as electric compass, indoor GPS or landmark recognizing by vision system. This paper presents a sensor fusion localization method by optimal combination of encoder sensor and landmark recognizing method by vision sensor module(STARGAZER). The position error estimated by absolute sensor such as vision system is increased especially when the landmark image is captured during robot is moving. In this paper, a filtering method for removing the wrong estimated position was also proposed. For natural motion of the robot an effective weights control method of position and orientation rate was proposed. We proved this system's validity through field test

Keywords: mobile robot, localization, sensor fusion

I. INTRODUCTION

The goal of this work is to implement an autonomous mobile robot capable of navigating in an unknown indoor environment. For this, the robot requires the capability to estimate accurate position and to build a map of the environment while the robot moving in the indoor space. Map building and navigation is a complex problem because map integrity and localization cannot be sustained by odometry alone due to errors introduced by wheel slippage and distortion. Moreover, neither odometry nor absolute sensory data gives perfect estimation of the robot's position. This paper employs absolute and relative positioning for accurate position estimation in the map building process and navigation. Relative positioning is usually based on odometry, that is, computing a robot's relative motion from the measurement of wheel revolution. In most mobile robots, odometry is implemented by means of optical encoders that monitor the wheel revolutions. A positioning by odometry is simple and fast method to estimate the position and orientation of the moving robot. However, there are some systematic and non-systematic errors in detecting the correct position. Moreover, the errors continuously accumulate. Therefore, the odometry needs to be correct from time to time. The disadvantage of odometry is its unbounded accumulation of errors. To cope with this problems, Absolute position correction is necessary, and they are usually based on external measurements such as electric compass, indoor GPS or landmark recognizing by vision system. This paper presents a sensor fusion localization method by optimal combination of encoder sensor and landmark recognizing method by vision sensor module (STARGAZER). The position error estimated by absolute sensor such as vision system is increased especially when the landmark image is captured during robot is moving. In this paper, a filtering method for removing the wrong estimated position was also proposed. For natural motion of the robot an effective weights control method of position and orientation rate was proposed. The paper is organized as follows: Section 2 describes properties of odometry errors. Section 3 presents a sensor fusion localization method using absolute sensor and relative sensor. Section 4 describes an effective weight control method of position and orientation rate for natural robot moving. Section 5 represents the developed Linux based robot control structure which can deal with multiple sensors effectively. Section 6 and 7 provide successful experiment results for navigation and obstacle avoidance, and conclusions, respectively.

II. A SENSOR FUSION localization method

using absolute sensor and relative sensor

Encoder is low cost and easily equipped relative sensor for position estimation of the mobile robot. A localization by encoder sensor is simple and fast method to estimate the position and orientation of the moving robot. In the differential-drive design of two wheel mobile robot, incremental encoders are mounted onto the two drive motors to count the wheel revolution. Using simple geometric equations, it is straight-forward to compute the momentary position of the vehicle relative to the known starting position. The basic localization equations by using incremental encoder data are given as Eq.(1), (2) and (3).

$$\Delta\theta(t) = \frac{2\pi R}{N} \cdot \frac{\Delta C_R(t) - \Delta C_L(t)}{D} \qquad (1)$$

$$\Delta x(t) = \frac{2\pi R}{N} \cdot \frac{\Delta C_R(t) + \Delta C_L(t)}{D} \cdot \cos(\theta(t) + \frac{1}{2}\Delta\theta(t)) \qquad (2)$$

$$\Delta y(t) = \frac{2\pi R}{N} \cdot \frac{\Delta C_R(t) + \Delta C_L(t)}{D} \cdot \sin(\theta(t) + \frac{1}{2}\Delta\theta(t)) \qquad (3)$$

$$\theta(t) = \theta(t - \Delta t) + \Delta\theta(t) \qquad (4)$$

where R, N and D are the radius of wheel, gear rate and distance between wheels, respectively. Δenc_L and Δenc_R are incremental encoder values of right and left wheel, respectirely. For correcting the encoder localization errors, one should realize that there are a few types of error such as systematic errors caused by unequal wheel diameter, simple linealization of the odometry equations as Eq(1) thru (3), and non-systematic errors are caused by lippery floors. A localization by encoder sensor is simple and fast method to estimate the position and orientation of the moving robot. However, there are some systematic and non-systematic errors in detecting the correct position. Moreover, the errors continuously accumulate[5]. Therefore, the odometry needs to be correct from time to time. We propose a sensor fusion method to estimate the robot position using vision sensor module (STARGAZER) and encoder sensor. The sensor estimate the position and heading angle of the robot by analyzing the infrared ray image which is reflected from different ID number-given passive landmarks on the ceiling. It has some drawback that its average position error is much larger than that of odometry , and the sensor can not find robot position when the robot is located in deadzone where the image can not be readable. Position error by image sensor is larger than that by encoder sensor, when the robot follows the straight line path. On the other hand, when the robot moves in corner or circular path, The sensed error by encoder is larger than image sensor. To overcome the short coming of the two sensor and increase the advantages, we propose a sensor fusion method by using absolute and relative sensors.

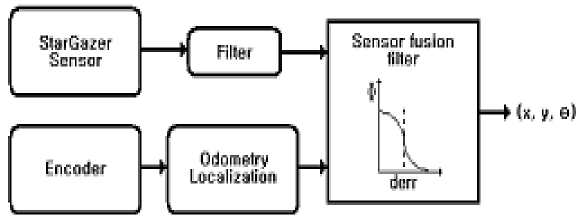


Fig1. The absolute and relative sensor fusion for localization

The Fig 1 represents the block diagram of the proposed sensor fusion method using encoder sensor and image sensor module. The encoder sensor and image sensor module detect the relative position and absolute position of the mobile robot, respectively . The two sensor data are fused by sigmoid function filter as Eq(4) . Xa is a localization position velocity after sensor fusion. The sigmoid function is defined by Eq(5). Where perr is absolute difference value between sensed value by image sensor (Xsg) and sensed value by encoder (Xe). The sensor fusion system described by Eq(5),(6) and (7) is designed by following idea. (1) if the distance error perr is larger than the limit value of image sensor , then the reliable value is that from image sensor, (2) if the perr is smaller than derr, then the appropriate localization value is mixed one of image sensor and encoder and (3) the smaller perr is, the more reliable encoder position localization is. The larger perr is, the more reliable image sensor localization is

$$X_a = (1 - \Phi)X_{SG} + \Phi \cdot X_E \qquad (5)$$

$$\Phi = 1 - \frac{1}{1 + e^{-(perr + derr)\cdot k}} \qquad (6)$$

$$perr = \sqrt{(X_{SG} - X_E)^2 + (Y_{SG} - Y_E)^2} \qquad (7)$$

III. AN EFFECTIVE WEIGHT CONTROL METHOD OF POSITION AND ORIENTATION RATE FOR NATURAL ROBOT MOVING

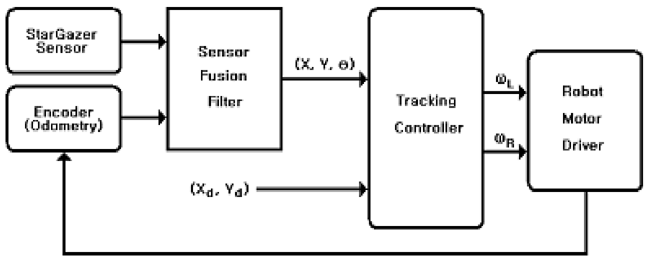


Fig. 2 Block diagram of position controller.

Two wheel velocity commands are decided by Eq.(8)

thru Eq(12). Where γ_1 control the linear velocity of the robot. And γ_2 control the rotation velocity. For the natural motion, it is better for the robot to control direction toward goal position during first 25% of moving distance, and the robot move linearly to the goal during the last 75% distance. These motion can be possible by control the weighting factors γ_1 and γ_2. γ_1 is decided by Eq.(9), where L0 is distance between starting position and goal position. Delta Li is distance between current position and goal position. If we decide the Kg1 and delta L0 as 20.0 and 0.25, then the motion of the robot will be like the trajectory as shown Fig.3.

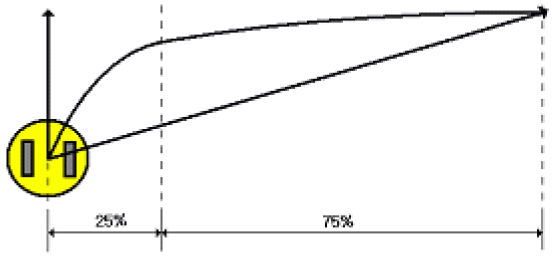


Fig.3 Trajectory of the robot controlled by factors γ_1 and γ_2.

$$\omega_R = V_d\gamma_1 + \gamma_2(kr_p\theta_e + kr_d\dot{\theta}) + \gamma_3 k_{o_R} \tag{8}$$

$$\omega_L = V_d\gamma_1 - \gamma_2(kr_p\theta_e + kr_d\dot{\theta}) - \gamma_3 k_{o_L} \tag{9}$$

$$\gamma_1 = 1 - \frac{1}{1 + e^{-(\delta l_i / L_0 - \delta L_0 / 2)\cdot kg_1}} \tag{10}$$

$$kg_1 = 20.0,\ \delta L_0 = 0.25 \quad \begin{matrix} \omega_L \le |\omega_{L\max}| \\ \omega_R \le |\omega_{R\max}| \end{matrix} \tag{11}$$

$$\delta L_i = \sqrt{(X_f - X_o)^2 - (Y_f - Y_o)^2} \tag{12}$$

γ_3 is controllable weighting factor for obstacle avoidance. Since the larger γ_3 is, the robot rotates more fast, if the factor γ_3 is controlled according to the distance between robot and obstacle, robot can avoid the moving or static obstacle. The approach velocity to the goal position controlled by γ_1 . Therefore, The appropriate change of γ_1, γ_2 and γ_3 can make the robot move to the goal position while avoiding the obstacle.

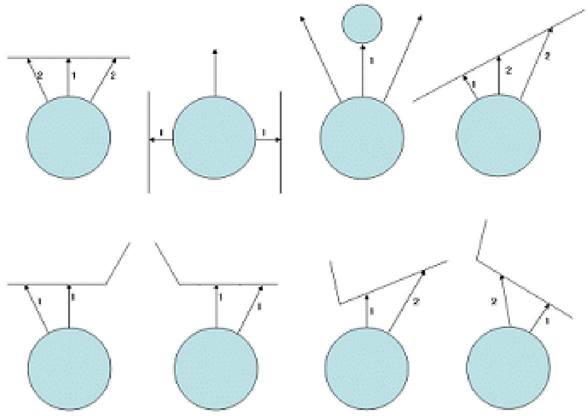


Fig. 4. Obstacle sensing and avoiding according to various obstacle types.

IV. EXPERIMENT RESULTS

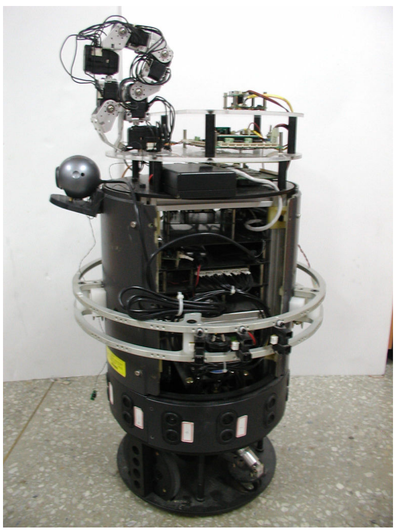


Fig.5 Developed mobile robot and sensor fusion contol system

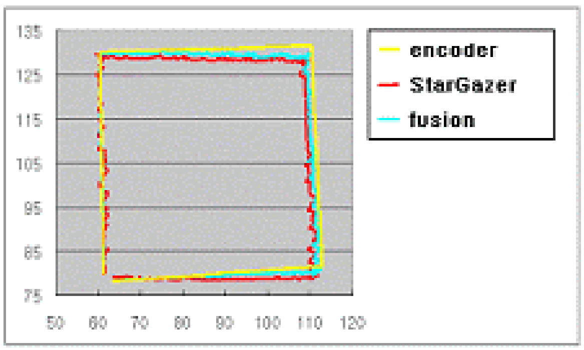


Fig.6 Rectangle trajectories with 3 control method.

The developed sensor controller for sensing of multiple sensor and mobile robot is shown in Fig. 5. Localized trajectories estimated by image sensor module and encoder data are shown in Fig 6. The desired trajectory is rectangle path of 50cmX50cm. The trajectory drawn with bold line is desired one and the trajectory drawn with yellow line is resultant path estimated by odometry. There are some error in edges of the rectangle trajectory owing to slipping and simple linearization of the odometry equation. The trajectory localized by image sensor module is shown in red line. The trajectory has error like noise type. The errors were distributed in whole trajectory, but the errors were not accumulated. The errors in line path of trajectory localized by encoder sensor were much smaller than that by image sensor. Fig.7 shows the result of the proposed natural motion control method by equation (8) thru equation (11). We can see that our proposed method control the rotation and linear velocities well.

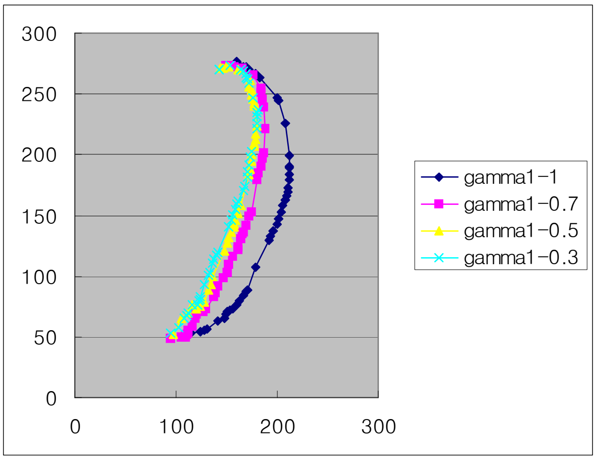
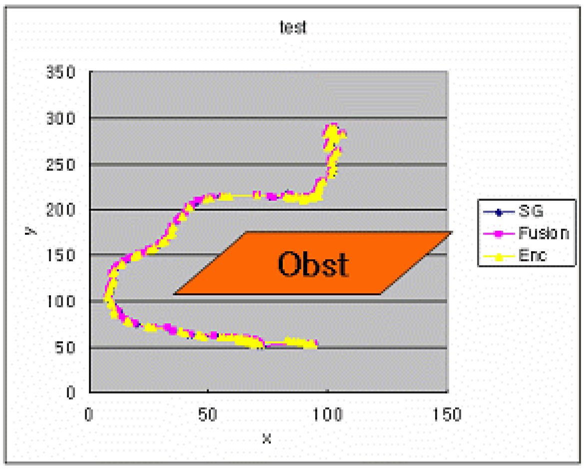


Fig.7 Trajectories with various γ_1 and γ_2 are changed

Obstacle avoidance trajectory while robot moving to the goal position is shown in Fig.8. The robot can avoid the obstacle with control of γ_3 and move to goal position with γ_1 and γ_3.



VI. CONCLUSION

This paper presents a sensor fusion localization method by optimal combination of encoder sensor and landmark recognizing method by vision sensor module(STARGAZER). The position error estimated by absolute sensor such as vision system is increased especially when the landmark image is captured during robot is moving. In this paper, a filtering method for removing the wrong estimated position was also proposed. For natural motion of the robot an effective weights control method of position and orientation rate was proposed.

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