ROBUST MOBILE ROBOT SELF-LOCALIZATION SYSTEM WITH SENSOR FUSION

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Abstract: This paper describes an efficient and robust localization system for autonomous mobile robot navigation in a structured indoor environment. In this system, artificial landmark-based localization algorithm is proposed to localize the mobile robot. To obtain the information required for the localization process, a camera and three ultrasonic sensors are used. Vision based localization system can benefit from using with ultrasonic sensors. Sensorfusion is performed at the detection of landmarks to be more precisely.The system will make landmark detection by using the data from camera when front ultrasonic sensor gets the distance (100 ~ 120cm) from the wall which is in front of the robot.The system only need to focus on the probable area which has landmark so it can reduce computational time. Sensor fusion is applicable for mobile robot navigation. This proposed algorithm is based on KalmanFillter (KF), which utilizes the data between observed and detection of artificial landmarks, to correct the position and orientation of the vehicle.The experimental results of the proposed system prove that both reliability and precision of the environmental observations used for the self-localization problem of mobile robot are more efficient.

Keywords: Artificial landmarks, Kalman filter, Localization, Mobile robot, Navigation, Ultrasonic sensors.

I. INTRODUCTION

When a mobile robot travels in an unknown or partially known environment, it must use various sensors to recognize the environment. Reliable and accurate sensing of the environment of a mobile robot is an important task in localization system. Mobile robots can be equipped with a variety of sensors, enabling the robot to gain some knowledge about its environment. The most common sensors are the infrared and ultrasonic sensors. On the other hand, computer vision can be applied for robot navigation, using such as monocular or stereo vision [1]. One of the major problems in intelligent mobile robots concerns extracting and fusing data from multi-sensor systems to acquire more accurate information about the environment and also decrease the uncertainties. If a robot needs to gain a more or less complete information of its environment, it cannot rely only on one type of sensor. Since a single sensor is not capable of doing the task, sensor fusion rises in importance. Information from different sensors are obtained and combined to find the location of the robot, detect obstacle and avoid it.

In this paper, the system uses a camera and three ultrasonic sensors for mobile robot localization system. Camera is used for getting data to make artificial landmarks detection that can be along the robot moving way in structured indoor environment. And three ultrasonic sensors are used for wall and obstacles detection to prevent from collision while making localization and also to get the distance between the robot and the landmark. Ultrasonic sensors have been widely used in robotics for obstacle avoidance mainly due to their simplicity and relatively low cost. This type of sensors are very good in distance measurement of the obstacles [2]. On the other hand, cameras are useful for getting information from the environment. In this work, three ultrasonic sensors and a camera were combined to provide a sensor system for a mobile robot. These two types of data have their advantages and are very often used in robotic applications, but combining them provides even more useful information.

For localization problem, the robot has to find out its location relative to the environment. In this system, the robot can know its location with respect to the artificial landmarks that are placed in the environment. So, a camera is mounted on top of the robot and in fixed orientation to look ahead the artificial landmarks in the environment. Artificial Landmarks are used to reduce uncertainty in the environment of mobile robot. Landmark detection and recognition are needed to make pose estimation. An accurate solution of the localization problem is important for properly initializing the navigation filters so Kalman filter is used. Using Kalman Filter (KF) can make more efficient the localization method of the object [3]. To correct the position and orientation of the vehicle, KF can reduce the error between the observed and estimated robot–landmark angles, and the distances between the robot and the things in the environment (walls, doors, etc.). The Kalman filter is a linear, discrete-time system. The proposed sensor fusing algorithm also provides constraints that filter out unreliable data from the sensor readings. Kalman filter (KF) has been designed for raw sensor data fusion to obtain more reliable representation in environment perception procedures. For localization and obstacle avoidance, data from sensors can be fused to get the location of the mobile robot in the environment. The rest of this paper is organized as follows: Section II describes the related works of localization system. In Section III,

sensor data fusion system is explained. Landmark based representation of the environment is described in section IV. The experimental results of the system are described in Section V. And then discussion and conclusion in Section VI.

II. RELATED WORKS

Sensor fusion has been subject to a lot of research, most of the proposed methods use Kalman Filtering and Bayesian reasoning. However, in recent years, there has been a tendency to make more and more use of soft computing techniques such as artificial neural networks and fuzzy logic for dealing with sensor fusion. A typical system is described in Escalera et al. [4], where a combination of a laser diode and a CCD camera is used. In [5], a sonar localization system for mobile robot navigation in a known environment is described; state corrections are applied through a standard Kalman filter. In [6], an application of the EKF to the problem of mobile robot navigation in a known environment is presented. This navigation algorithm is based around an EKF, which utilizes matches between observed geometric beacons and an a priori map of beacon locations.

Hu and Gu used laser scanners for landmark position estimation and robot localization in manufacturing industry [7]. Their system updates landmarks in a dynamic environment. Many landmark based or map based algorithms have been proposed by using range sensors [8, 9]. As the vision technology develops, vision sensors are being widely used for mobile robot localization and navigation. The landmark positioning idea was applied to the vision sensor system for 2-Dimensional localization using a single camera in [10]. A method that uses a stereo pair of cameras was developed to determine the correspondence between the observed landmarks and the pre-loaded map and to estimate the 2-D location of the sensor from the correspondence [11].

Utilizing artificial landmarks offers the possibility of improving the reliability of the localization. Some approaches consider artificial landmarks that can be uniquely identified. In this paper, sensor fusion system and visual pattern landmarks are used to reduce uncertainty for localization system.

III. SENSOR DATA FUSION SYSTEM

The sensor system consists of a camera and three ultrasonic sensors. All three ultrasonic sensors are mounted on the mobile robot that two of which are mounted on each side of the vehicle and one is in the front. The ultrasonic sensors are capable of performing accurate distance measurements and help to build up a map of the environment. A camera is mounted on top of the vehicle. Camera can be used by a localization system to detect, identify, and estimate the pose of objects in a scene with respect to the camera's coordinate system.

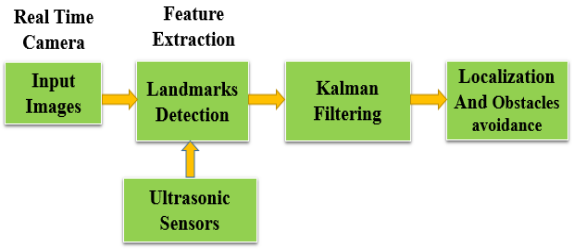


Fig.1. System Block Diagram

The system block diagram of the mobile robot is described in Fig.1.If the system gets distance between robot and landmark (100 ~ 120cm) from front ultrasonic sensor, it will make landmark detection by using the data from camera. Landmarks are detected by using Canny edge detection and Chain-code Approximation algorithms to represent the contour of landmarks by using edge points.The robot uses a camera and ultrasonic sensor to obtain the information and these measurements include a component error. So, Kalman filter is used to integrate measurement data into an estimate by recognizing that measurements. The robot estimates its current position by updating with the filter results. The robot can get less errors in pose estimation after applying and calculating the data with Kalman filter. When the robot finishes updating its current state, it can know the position in its environment. Then, it sends data to the control board to drive and continues the localization system. The robot can make localization more accurately by calculating the received data with Kalman Filter.

3.1. Ultrasonic Sensor

Ultrasonic sensors are often called transducers. Using ultrasonic sensors, presence of an object can be easily detected. The ultrasonic sensor will always release ultrasonic wave [12]. The time difference between the transmission of the ultrasonic wave and the reception of the reflected wave is calculated. Since the speed of the sound wave can know, the system can calculate the distance of the obstacles and landmark.

$$\text{Distance} = \text{speed} \times \text{time} \qquad (1)$$

The ultrasonic sensors have emission frequencies of 56 kHz. The sensors used in this work have a range of about 0.30 m to 10 m. Their limited field of view and low angular resolution are compensated as much as possible by using intelligent processing techniques.

3.2. Camera

Cameras can be considered as cheap sensors compared to laser scanners, and visual data can be used to solve ambiguous situations [13]. The proposed method uses two-dimensional camera images which provide robot's localization algorithm with more data about the environment.

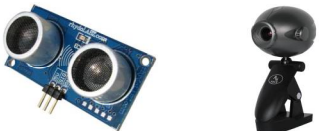


Fig.2. Ultrasonic Sensor and USB Camera

An image processing board raspberry pi and the software, Open CVare used for processing of that image. The camera, with a resolution of 640 x 480 pixels was fixed. The pose of the object can then be inverted to estimate the camera's pose with respect to the object's coordinate system. USB camera and ultrasonic sensor that are used in the system are shown in Fig.2.

3.3. Data Fusion of Sensors with Kalman Filter

The system uses the range data collected by the ultrasonic sensors with the images captured by the camera for landmark detection and distance measurement. Block diagram of the proposed sensor system is shown in Fig.3.For an autonomous mobile robot, sensor fusion is important to perceive its environment. Without knowing the surroundings it is not possible for it to navigate around. An autonomous robot moves unsupervised. It obtains information of surrounding environments using its sensors and decides its course of action according to its programming.

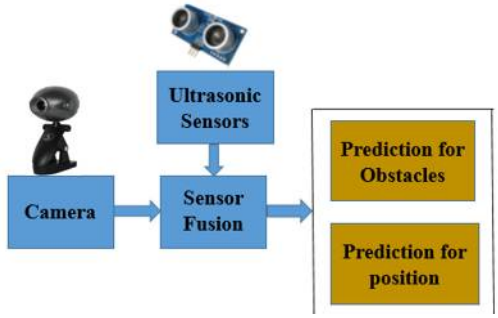


Fig.3. The proposed block diagram for sensor fusion

If the information provided is inaccurate or incomplete, it becomes hard for the robot to decide its next action.Not to do so, the system firstly detects the existence of wall which has landmark, in front of the robot. It only detects the landmark that is in the front wall, not on the sides. If the system gets the distance between the robot and front wall within the detection range, it will make landmark detection by fusion with the data of visual system by using image processing techniques. To make pose estimation, the system is necessary to find the region of interest (ROI) at the centre of the detected artificial landmark in the coordinate frame fixed to a camera in the case of localization using the images captured by the camera.Viewing angle of the camera and landmark detection area of the ultrasonic sensor is shown in Fig.4.

Kalman Filter is used to combine the information from sensors to estimate the state and the location the robot. The system is linear and described by system model.

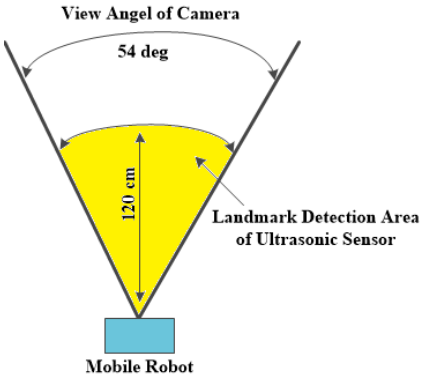


Fig.4. View angle of the camera and landmark detection area of the ultrasonic sensor

KF: Prediction Step

The system calculates the initial state or previous state estimate, $\hat{X}_{k|k-1}$ by combining prior knowledge, prediction from system models, and noisy measurements.

$$\hat{X}_{k|k-1} = A\hat{X}_{k-1|k-1} + Bu_k \quad (2)$$

Where u_k is the vector containing control inputs (steering angles, braking force), A is the state matrix which applies the effect of each system state parameter at time transition k-1 on the system state at time t and ***B*** is the control input matrix which applies the effect of each control input parameter in the vector u_k on the state vector. To describe the Gaussian functions, need to know their variances and covariance, and these are stored in the covariance matrix $P_{k|k-1}$.

$$P_{k|k-1} = AP_{k-1|k-1}A^T + Q \quad (3)$$

The main diagonal of $P_{k|k-1}$ are the variances associated with the corresponding terms in the state vector. The off-diagonal of $P_{k|k-1}$ provide the covariance between terms in the state vector.

KF: Updating Step

1. Kalman Gain

The Kalman gain is calculated by using data of error in estimate, $P_{k|k-1}$ and error in measurement, R. The resulted value Kalman gain is between 0 and 1 $(0 \le J_k \le 1)$.

$$J_k = \frac{P_{k|k-1}C^T}{(CP_{k|k-1}C^T + R)^{-1}} \quad (4)$$

2. Current Estimate

It can be calculated by the data from previous estimate, $\hat{X}_{k|k-1}$ and the measurement value, Y_k.

$$\hat{X}_{k|k} = \hat{X}_{k|k-1} + J_k(Y_k - C\hat{X}_{k|k-1}) \quad (5)$$

3. New Error in Estimate

$$P_{k|k} = (I - J_k C)P_{k|k-1} \quad (6)$$

From landmark detection, the system gets position and orientation. The robot firstly estimates the position by depending on the initial position state. Then, the system calculates the Kalman gain, J_k from the errors in estimate and data measurement. And then, the current estimate, $\hat{X}_{k|k}$ is calculated by the previous estimate and the measurement value. After that new error in the estimate, $P_{k|k}$ is calculated to make next pose estimation.

IV. LANDMARK-BASE REPRESENTATION OF THE ENVIRONMENT

One way of resolving uncertainty in the environment is to use artificial landmarks. Uncertain environments make the localization approaches more likely to fail. Utilizing artificial landmarks offers the possibility of improving the reliability of the localization. In this paper, visual pattern landmarks are used to reduce localization uncertainties.

4.1. Artificial Landmark Designs

Artificial landmark is a specially designed object to be placed in the environment with the purpose of navigation. Artificial landmarks can be designed in order to be uniquely identified by sensor and this greatly simplifies the localization task. Artificial landmarks which are used for mobile robot self-localization, are shown in Fig.5.

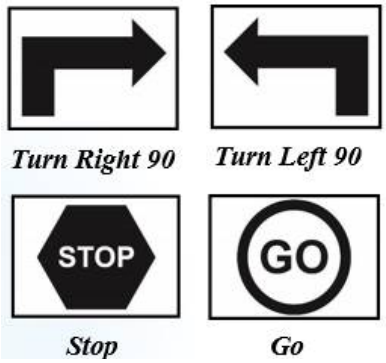


Fig.5. Signs of Artificial Landmarks

4.2. Landmark Detection

Landmark detection will have to make to know the location of the mobile robot. The mobile robot captures images in its surrounding and makes image processing when it found landmark. The results of the detected artificial landmark with landmark detection steps are shown in Fig.6.

In this system, landmark detection method is applicable to mobile robot localization. It proved to achieve solutions with less computational times which provide detection more precisely whatever the landmark position. The processing results for artificial landmarks precise detection are shown in Fig.7.

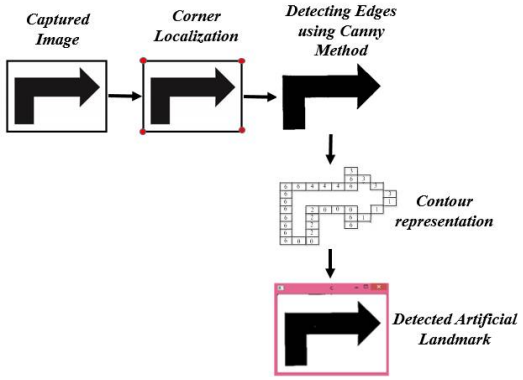


Fig.6. Detection steps for artificial landmarks

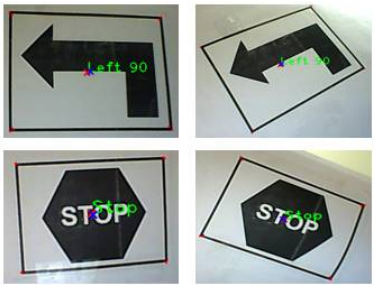


Fig.7. Detectable pictures of landmarks

V. EXPERIMENTAL RESULTS

The application written for this research relies heavily on the vision and image processing system for which there exists an open source library named OpenCV.

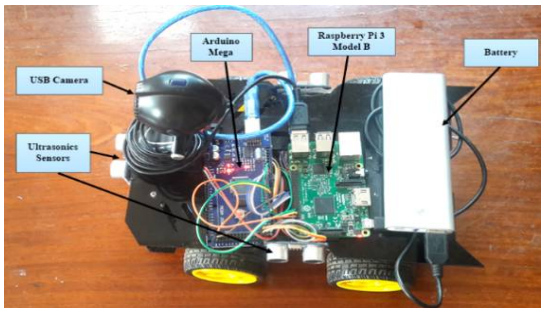


Fig.8. Mobile Robot

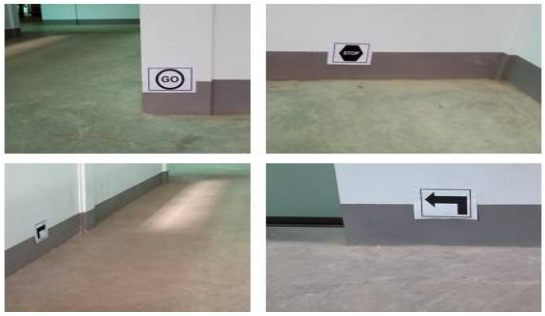


Fig.9. Artificial landmarks placement in structured indoor environment

Having Linux support, this is the perfect choice for developing an application specifically for a Raspberry

Pi based system. Another positive aspect of this library is that it's written natively in C++ and therefore can be very smoothly implemented in a C/C++ application. The wheel motors of the mobile robot are controlled by a controller which get data from raspberry pi and arduino. The mobile robot for localization system and artificial landmarks placement are shown in Fig.8 and 9.

5.1. Localization

Artificial landmark-based localization algorithm is proposed to localize the mobile robot. The robot will detect only the landmarks which is in front of the vehicle in the environment.



Fig.10. Initial state detects nothing

If the system gets distance between robot and landmark (100 ~ 120cm) from front ultrasonic sensor, it will make landmark detection by using the data from camera.The system can reduce computational time because it only need to focus on the probable area which has landmark. Fig.10 – 13 shows the experimental results of mobile robot self-localization in a structured indoor environment.

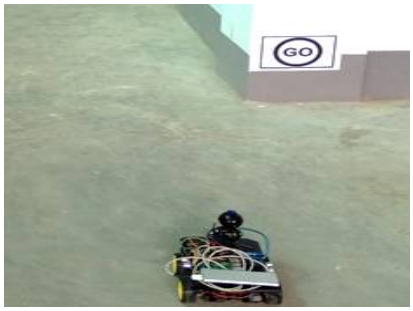


Fig.11. Detect landmark and move



(a) (b)

Fig.12. (a) Detect landmark, (b) Turn left and move

After landmark detection, the robot will know how to act and where to go by extracting the landmark signs which are directed. When the robot knows its way where to go, it will detect nothing for a while until it finds next landmark,except obstacle and wall detection. The robot moving and working process of turning left and right are shown in Fig.11 – 13.



(a) (b)

Fig.13. (a) Detect landmark, (b) Turn right and move

The stop sign detection and working process system of mobile robot is shown in Fig.14.

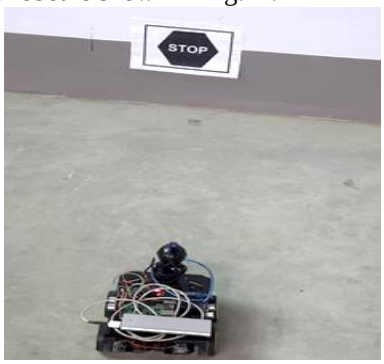


Fig.14. Detect stop landmark and then stop

Location	Errors by using Camera only	Errors by using Sensor Fusion
X-axis	10.9 %	5.6 %
Y-axis	9.8 %	3.9%

Table 1: Comparison of measurement errors

The experimental results have confirmed the capability and performance of the proposed system. The results of applying sensor fusion was presented for localization and to the navigation of a mobile robot.In Table 1, the results of the measurement errors for using only one camera and using a camera and ultrasonic sensors (sensor fusion) are shown with comparison. The system can reduce the localization errors by using sensor fusion technique.

CONCLUSIONS

The proposed algorithms could estimate the robot pose reasonably well and could accurately evaluate the localization performance. Sensor fusion was allowed the robot to perceive its surroundings like human beings. Information from one sensor alone was not enough to give accurate information. One major advantage of sensor fusion was the availability of multiple sources of data, through which the robot may verify the readings of its individual sensors and reduce the overall error of its pose estimates. The system was able to reduce the cost and computational time because of the sensor fusion and image processing techniques. Theenvironment mapping was considered as a future work.

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