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Mobile Robot Localization and Map Building for a Nonholonomic Mobile Robot

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1. Introduction

Mobile robot localization and map building are very important for a mobile robot to perform a navigation-based service task to aid the aged or disabled in an indoor environment (office, facilities or at home). In order to enable mobile robot to perform service tasks autonomously, the information of environment in which the mobile robot moves is needed. To obtain the accurate map, many different sensors system and techniques have been developed. Approaches of mapping can roughly be classified according to the kind of sensor data processed and the matching algorithms [S. Thrun et al., 1996, 1998, 2000, 2004; Chong, K.S et al., 1996; C.-C. Wang et al., 2002; G. Dissanayake et al., 2000; B. barshan et al., 1995; Weimin Shen et al., 2005]. In this paper, we proposed a method of map building using interactive GUI for a mobile robot. The reason we proposed this method is that it is difficult for a mobile robot to generate an accurate map although many kinds of sensors are used. The proposed method enables the operator to modify map built by sensors, compared with the real-time video from web camera by using modification tool in interactive GUI. Laser Range Finder (LRF) was used to get the information of the environment in which mobile robot moving. In order to improve self-localization of mobile robot, Extended Kalman Filter (EKF) was introduced. By the results of simulation and experiments, the developed EKF is effective in self-localization of mobile robot. This paper introduces the architecture of the system and gives some experimental results to verify the effectiveness of the developed system.

The rest of the paper consists of 5 sections. Section 2 describes the structure of the proposed system. Section 3 presents the developed algorithm of self-localization of mobile robot and gives some simulation and experimental results to verify the effectiveness of the EKF in improving precision of positioning of mobile robot. Section 4 details the developed LRF data processing algorithm. Section 5 introduces the developed interactive GUI. The experimental results are given in Section 6. Section 7 concludes the paper.

2. System Description

Figure 1 illustrates the architecture of the proposed system. It includes a nonholonomic mobile robot, Laser Ranger Finder (LRF), web camera, robot controller, data processing PC and GUI for operator. Data from LRF, odometry and real-time video from web camera are processed on data processing PC, and map is built according to the processed results. These results are transferred to the GUI PC and shown in GUI via Internet.
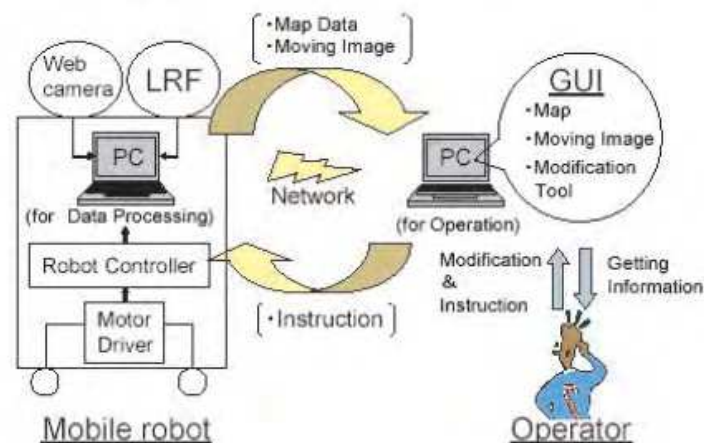
Fig. 1. The developed system architecture.

In the previously developed system, an omnidirectional mobile robot was used to perform service tasks. Owing to the specific structure of its wheel arrangement, it is difficult for a mobile robot to pass over a bump or enter a room where there is a threshold. Another important point is to lower costs and decrease the number of motors so that the battery can supply enough electricity for a mobile robot to run for a longer time. Figure 2 illustrates the developed mobile robot platform. In our new system, we developed a non-holonomic mobile robot that was remodelled from a commercially available manual cart. The structure of the front wheels was changed with a lever balance structure to make the mobile robot move smoothly and the motors were fixed to the two front wheels. It has low cost and can easily pass over a bump or gap between the floor and rooms. We selected the Maxon EC motor and a digital server amplifier 4-Q-EC 50/5 which can be controlled via RS-232C. For the controller of the mobile robot, a PC104 CPU module (PCM-3350 Geode GX1-300 based) is used, on which RT-Linux is running. For communication between the mobile robot and the mobile robot control server running on the host computer, a wireless LAN (PCMCIA-WLI-L111) is used.

Fig. 2. The developed mobile robot platform.

Laser Ranger Finder is a precision instrument based on Time of Flight principle. URG-X04LX (HOKUYO AUTOMATIC CO., LTD) was used in our system to detect the environment. It uses IR laser (wave length 785mm). Its distances range is about 60 to 4095mm 0-240°. The measurement error is about $\pm$ 10mm between 60 to 1000mm and 10% between 1000-4095mm. The scanning time for one circle is about 100ms.

The QuickCam Orbit cameras were used in our system to transfer the real-video for the operator with automatic face tracking and mechanical Pan, Tilt and face tracking feature. It mechanically and automatically turns left and right for almost a 180-degree horizontal view or up and down for almost 90 degree top-to-bottom view. It has high-quality videos at true CCD 640×480 resolution and its maximum video frame rate are 30 fps (frames per second) and work with both USB 2.0 and 1.1.

3. Self-Localization of Mobile Robot by Extended Kalman Filter

Odometry is usually used in relative position of mobile robot because it is simple, inexpensive and easily accomplished in real time, but it fails to accurately positioning over long traveling distance because of wheel slippages, mechanical tolerances and surface roughness. We use Extended Kalman Filter to improve self-localization for mobile robot. The Extended Kalman Filter algorithm [Greg Welch et al., 2004] is recursive and only the current state calculation will be used, so it is easy to implement. In order to use EKF, we have to build system state model and sensor model. The movement model of mobile robot used in our system was shown in Figure 3. v_{Rk}, v_{Lk} are the speed of right wheel and left wheel, l is the distance between two wheels, w_k is the system error, and assumed to be white Gaussian with covariance W_k. The movement model of mobile robot can be defined as equations (1)-(6), and the state model can be defined as equation (7).

Equations (8)-(12) are the observation model. LRF detects wall or corner of environment as Landmarks for observation model. Equations (15)-(21) give the recurrence computation for predetecting and updating of the state of the mobile robot.
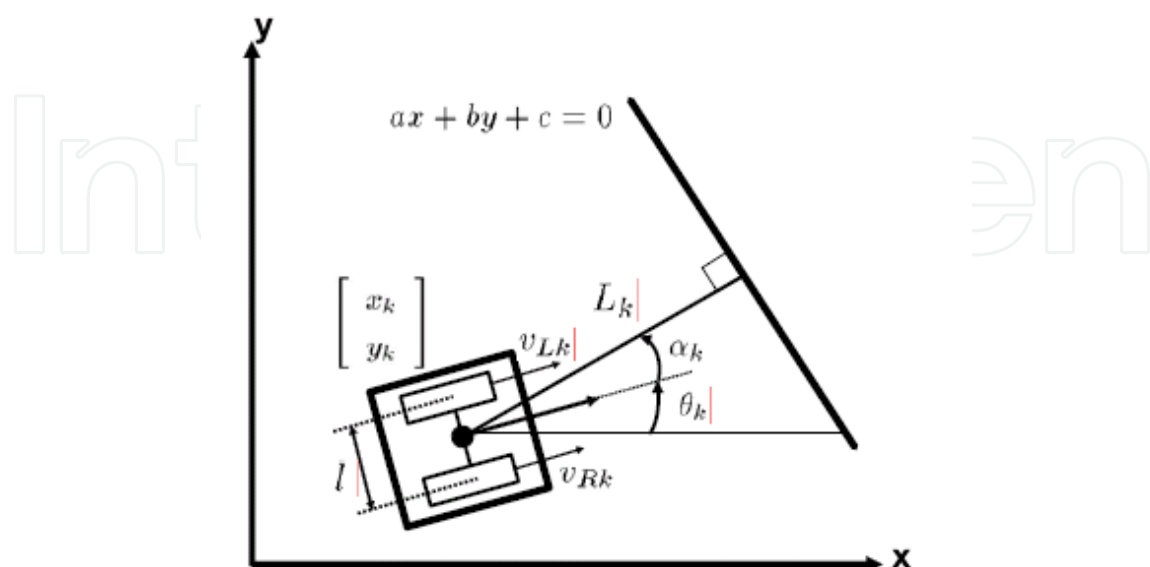

Fig. 3. Movement model of mobile robot platform.

$$\mathbf{x_k} = \begin{bmatrix} x_k \\ y_k \\ \theta_k \end{bmatrix} \tag{1}$$

$$\mathbf{u_k} = \begin{bmatrix} v_{Rk} \\ v_{Lk} \end{bmatrix} \tag{2}$$

$$x_{k+1} = x_k + \frac{v_{Rk} + v_{Lk}}{2} cos\theta_k \cdot \Delta t \tag{3}$$

$$y_{k+1} = y_k + \frac{v_{Rk} + v_{Lk}}{2} sin\theta_k \cdot \Delta t \tag{4}$$

$$\theta_{k+1} = \theta_k + \frac{v_{Rk} - v_{Lk}}{l} \cdot \Delta t \tag{5}$$

$$f(\mathbf{x_k}, \mathbf{u_k}) = \begin{bmatrix} x_k + \frac{v_{Rk}+v_{Lk}}{2} cos\theta_k \cdot \Delta t \\ y_k + \frac{v_{Rk}+v_{Lk}}{2} sin\theta_k \cdot \Delta t \\ \theta_k + \frac{v_{Rk}-v_{Lk}}{l} \cdot \Delta t \end{bmatrix} \tag{6}$$

$$\mathbf{x_{k+1}} = \mathbf{f}(\mathbf{x_k}, \mathbf{u_k}) + \mathbf{w_k} \tag{7}$$

$$\mathbf{y_k} = \begin{bmatrix} L_k \\ \alpha_k \end{bmatrix} \tag{8}$$

$$L_k = \frac{\mid ax_k + by_k + c \mid}{\sqrt{a^2 + b^2}} \tag{9}$$

$$\alpha_k = tan^{-1}(-\frac{a}{b}) - \frac{\pi}{2} - \theta_k \tag{10}$$

$$h(\mathbf{x_k}) = \begin{bmatrix} \frac{|ax_k+by_k+c|}{\sqrt{a^2+b^2}} \\ tan^{-1}(-\frac{a}{b}) - \frac{\pi}{2} - \theta_k \end{bmatrix} \tag{11}$$

$$\mathbf{y_k} = \mathbf{h}(\mathbf{x_k}) + \mathbf{v_k} \tag{12}$$

$$\mathbf{v_k} \sim \mathbf{N}(\mathbf{0}, \mathbf{V_k}) \tag{13}$$

$$\mathbf{V_k} = \begin{bmatrix} \sigma_L{}^2 & 0 \\ 0 & \sigma_\alpha{}^2 \end{bmatrix} \tag{14}$$

System state one-step prediction $\hat{x}_{k+1}$ and its associated covariance $\hat{P}_{k+1}$ can be calculated from previous k and previous $\hat{x}_k$ and $\hat{P}_k$ (equation (15)-(16)). The state update can be done using equation (19)-(21).

$$\hat{\mathbf{x}}_{\mathbf{k+1}}(-) = \mathbf{f}(\hat{\mathbf{x}}_{\mathbf{k}}(+), \mathbf{u_k}) \tag{15}$$

$$\hat{\mathbf{P}}_{\mathbf{k+1}}(-) = \mathbf{F_k}\hat{\mathbf{P}}_{\mathbf{k}}(+)\mathbf{F_k^T} + \mathbf{G_k}\mathbf{W_k}\mathbf{G_k^T} \tag{16}$$

Here, $\hat{x}_k$ (+) is state estimation at t = k after observation. $\hat{x}_{k+1}$ is state estimation at t = k +1 before observation. $\hat{P}_k$ (+) is error covariance at t = k after observation. $\hat{P}_{k+1}$ (−) is error covariance at t = k+1 before observation. F_k, G_k can be calculated by the following equation.

$$F_k = \frac{\partial f(x, u)}{\partial x}\Big|_{x=\hat{x}_k(+), u=u_k} \tag{17}$$

$$G_k = \frac{\partial f(x, u)}{\partial u}\Big|_{x=\hat{x}_k(+), u=u_k} \tag{18}$$

$$K_{k+1} = \hat{P}_{k+1}(-)H_{k+1}^T(H_{k+1}\hat{P}_{k+1}(-)H_{k+1}^T + V_{k+1}) \tag{19}$$

$$\hat{x}_{k+1}(+) = \hat{x}_{k+1}(-) + K_{k+1}(y_{k+1} - h(\hat{x}_{k+1}(-))) \tag{20}$$

$$\hat{P}_{k+1}(+) = (I - K_{k+1}H_{k+1})\hat{P}_{k+1}(-) \tag{21}$$

Figure 4 illustrates the flowchart of the developed method of map building. First the robot system gets the information of environment of mobile robot moving in by LRF (distance and angle), then transforms the coordinates of the processed results of LRF data, and draws the results in local map. Using these results, the robot system can predict the $\hat{x}_{k+1}$ (−) using Extended Kalman Filter, get observation parameters and update $\hat{x}_{k+1}$ (+). Lastly, the robot system will transform coordinates of the results from local to global. If there are some errors in the map built by sensors, the operator can modify the map generated using modification tool in interactive GUI by comparing the processing results of sensors and real-time video.
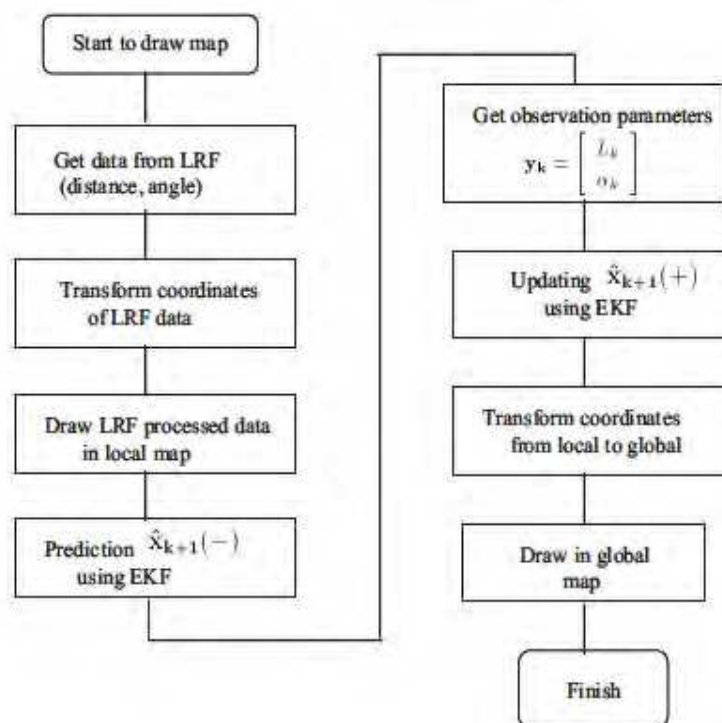

Fig. 4. Flowchart of the developed method of map building.

We have done simulations and experiments to compare the results of using Extended Kalman Filter and odometry. Figure 5 illustrates the some results of simulations and Figure 6 illustrates the experimental results of using developed mobile robot. The green line is the real trajectory of the mobile robot, the red line is the detected trajectory by using Extended Kalman Filter and the blue line is the trajectory detected by just odometry. According to these results, we know that the developed Extended Kalman Filter can improve the precision of self-localization of mobile robot.
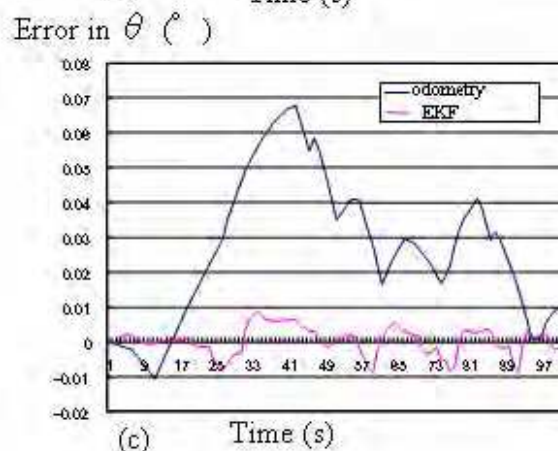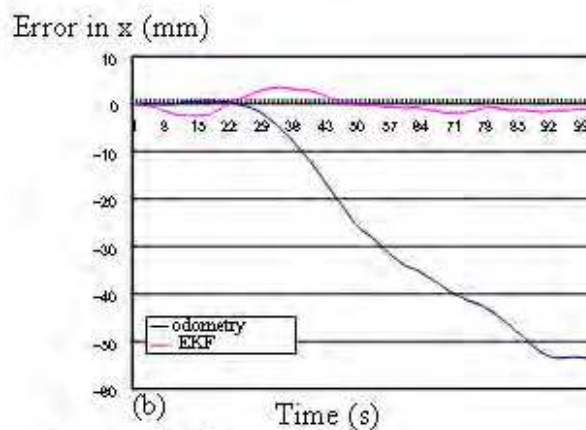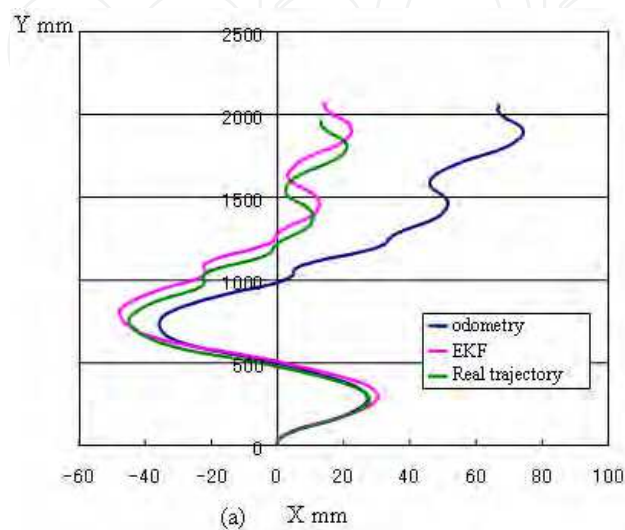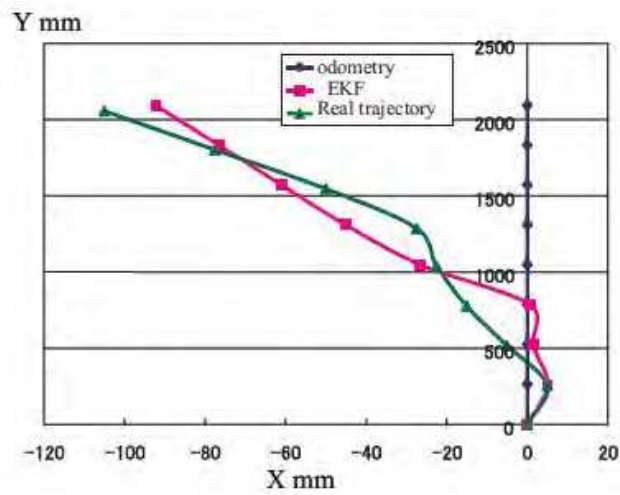
Fig. 5. Simulation results of using EKF.

Fig. 6. Experimental results of using EKF.
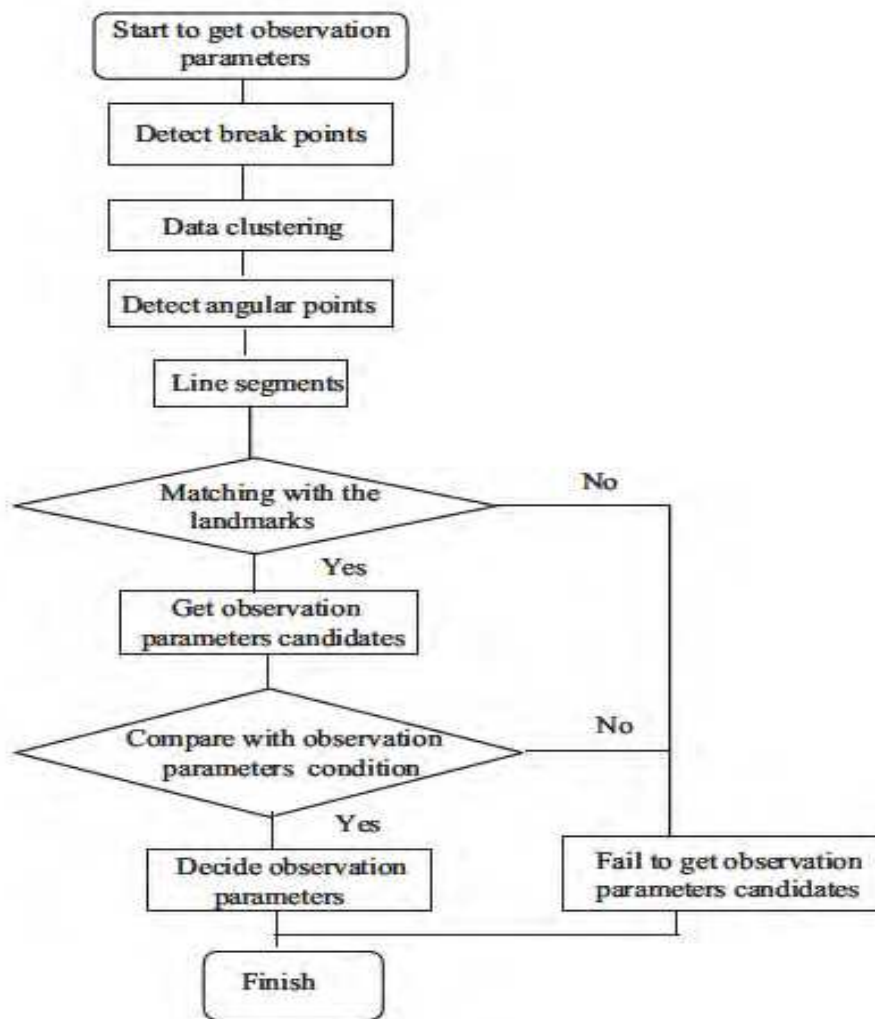
4. LRF Data Processing Algorithm

Fig. 7. Flowchart of LRF processing data.

It is necessary to process scanning data from LRF in order to get observation model parameters for map building of mobile robot. We proposed processing algorithm. Figure 7 illustrates the flowchart of the processing LRF data algorithm. It includes:
• Detect break points
• Data clustering
• Angular point's detection
• Line segment
• Match with landmarks
• Decide observation parameters candidate
• Decide observation parameters

4.1 Detect Break Points
Break points can be detected [Zhuang Yan et al., 2004] using the following equation (22) for total of 768 points of laser reading set per scan, here T_{BP} is the threshold given by experimental results in advance. Figure 8 illustrates the principle of detecting the break points.

$$|P_{i+1} - P_i| > T_{BP}, i = 0, ..., 766 \tag{22}$$
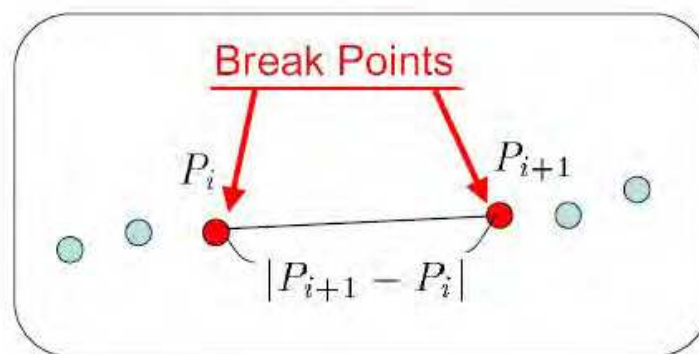

Fig. 8. Break Points detection.

4.2 Data Clustering
After break points were detected, we classified data into different clusters. If the data in one cluster (defined as N_{BP}) is smaller than T_{NBP} (threshold given by experimental results), the line segment in next section will be not done because the accurate results cannot be got.

4.3 Angular Points Detection
Figure 9 illustrates how to detect angular points. For the points $P_i, ..., P_{i+n}$ in each cluster, the slop from P_i to $P_{i+(n/2)}$ and from $P_{i+(n/2)}$ to P_{i+n} are calculated using the least squire method. If the ϕ satisfies the following condition, $P_{i+(n/2)}$ is detected as angular points. Here, T_{AP} is threshold given by experimental results.
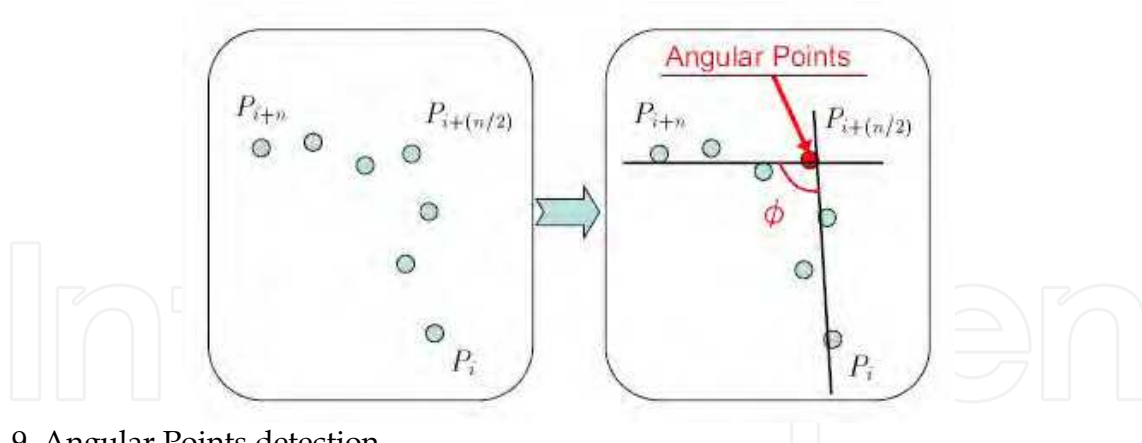
$$|\phi - \frac{\pi}{2}| < T_{AP} \tag{23}$$

Fig. 9. Angular Points detection

4.4 Line Segment

Using the angular points for each cluster, line features are extracted. Assume that the line expression is given by $y = g_{Gx} + i_G$, parameters g_G and i_G are calculated by the least square method. Figure 10 illustrates the flow of the line segment.
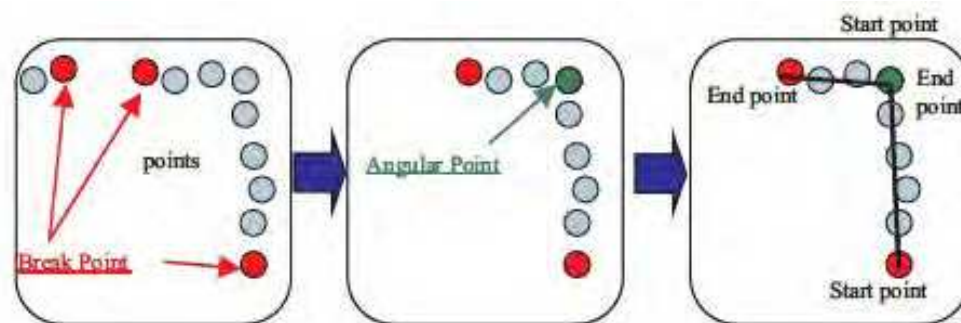

Fig. 10. Line segment.

4.5 March with Landmarks

Line extracted by above section was used to match with the landmarks. If the lines extracted satisfy the following conditions, matching is successful, otherwise matching failed. Here, T_g, T_i, $T_{b=0}$ are threshold.

$$\left| -\frac{a}{b} - g_G \right| < T_g \tag{24}$$

$$\left| -\frac{c}{b} - i_G \right| < T_i \tag{25}$$

In the case of $b = 0$, the condition will be:

$$\left| -\frac{c}{a} - i_G \right| < T_{b=0} \tag{26}$$

4.6 Decide Observation Parameters Candidate

For the lines that matching were successful, we calculated $\mathbf{y}_{k(candidate)} = [L_{k(candidate)} \; \alpha_{k(candidate)}]^T$ as observation parameters candidate.

4.7 Decide Observation Parameters

If there are multi-lines for one landmark, we have to extract one accurate line as observation model parameters from them. First the observation model parameters are calculated by each line extracted and if $L_{k(h)}$, $\alpha_{k(h)}$ satisfy the following condition, the observation parameters can be decided.

$$|\alpha_{k(min)} - \alpha_{k(h)})| < T_{\alpha} \tag{27}$$

$$|L_{k(min)} - L_{k(h)})| < T_L \tag{28}$$

Figure 11 illustrates some samples of processing LRF data. Figure 11(a) is data description from LRF; Figure 11(b) is the sample of detecting break points; Figure 11 (c) is the sample of detecting angular points; Figure 11 (d) is the sample of matching with landmarks.

(a)   (b)

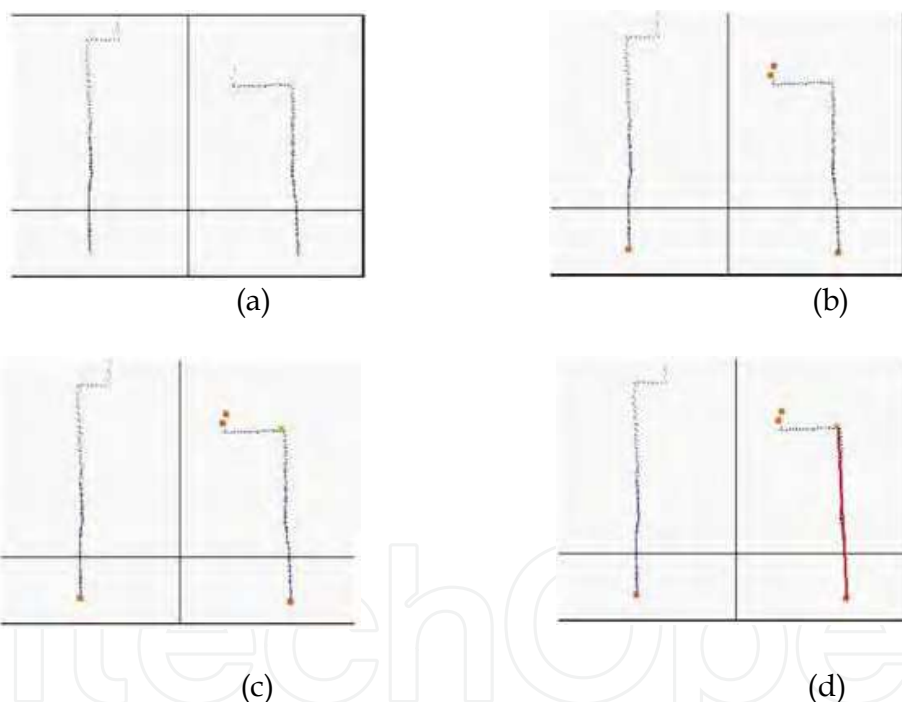(c)   (d)

Fig. 11. LRF data processing. (a) is data description; (b) is the sample of detecting break points; (c) is the sample of detecting angular points; (d) is the sample of matching with landmarks.

5. The Developed Interactive GUI

As described before, the reason we proposed this map building method is that it is difficult for a mobile robot to generate an accurate map although many kinds of sensors are used. We proposed map building method that enables the operator to modify map built by sensors, compared with the real-time video from web camera by using interactive GUI,

which can improve the precision of map building and simplify the system. Figure 12 illustrates the developed interactive GUI for the system. It includes:
• Display the map generated by sensors.
• Display the real environment of the mobile robot moving in.
• Pan and tilt control part for camera.
• Direct control function for mobile robot.
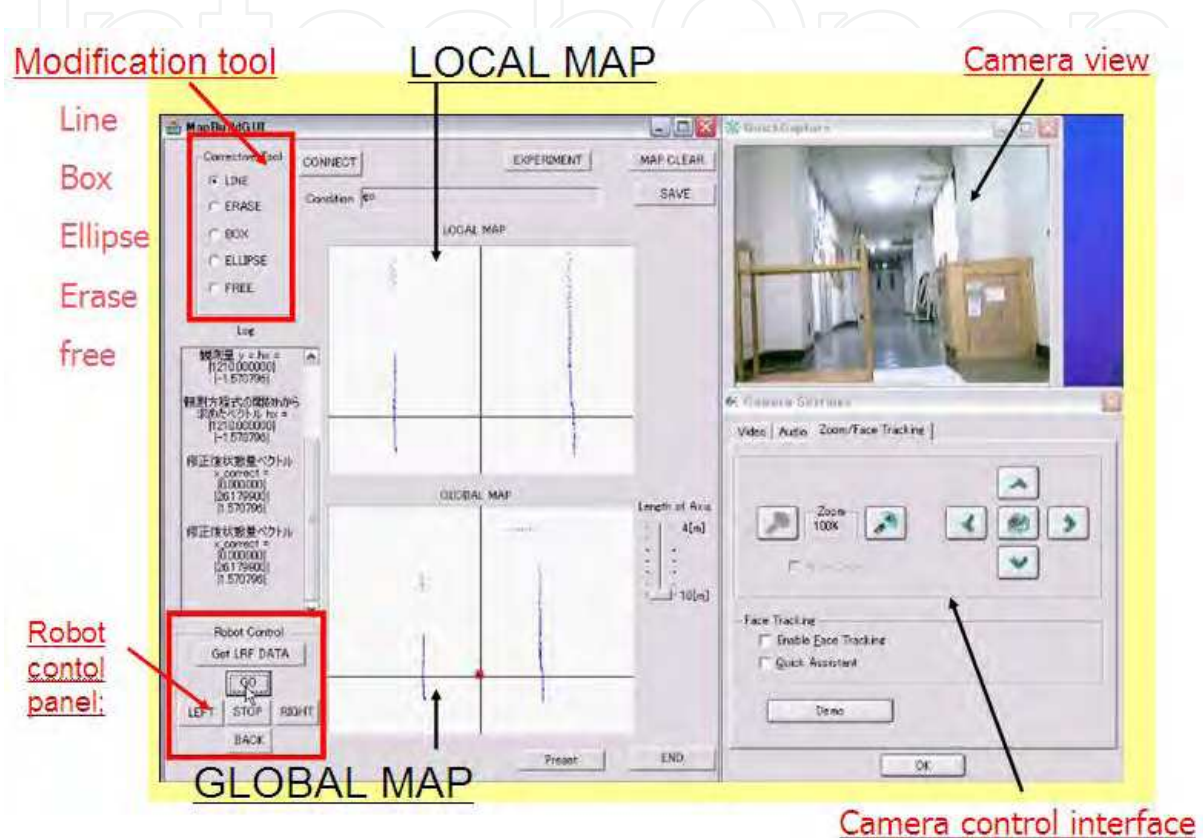• Modification tool for the operator to modify the map.

Fig. 12. The developed interactive GUI.

5.1 Map Display
Map first was generated from distance and angle data from LRF and odmetry from robot controller. The upper part is local area map about 4m×4m to display current map around the mobile robot in order for operator to observe accurately. The lower part is global map about 10m×10m to display all map built from the start moving position.

5.2 Display the Real Environment by Web Camera
In order for operator to monitor the real environment of the mobile robot moving and to modify the error of map, the QuickCam Orbit web camera was used to transfer real-time video and displayed in GUI. There are also pan, tilt and zoom modification control of camera in GUI to enable the operator to confirm the environment around the mobile robot.

5.3 Modification Tool for User to Modify the Map

Modification tool enables the operator to modify the error of map built by LRF and odemetry. Modification tool of map includes "Line, Box, Ellipse, Free, Erase" that enables the operator to modify the map generated by sensors if there are some errors in map built by sensors. For example, the operator can use "Box" in modification tool to draw the box in the map to modify the error of misrecognition of the bookshelf in the map because LRF just detected the feet part of bookshelf. Additionally, there are also the direct control function such as "move back, move forward, turn right, turn left, stop" to mobile robot in developed interactive GUI in order for operator to control mobile robot.

6. Experimental Results

We have done some simulations and experiments using EKF to improve the localization of mobile robot and the results verified that using EKF can enhance the precision of the localization of mobile robot. We have also done some experiments of map building using the proposed method, and some experimental results were shown in Figure 13 and Figure 14. Figure 13(a)-(d) are samples of the mobile robot moving for mapping; Figure 14(b) is the designed GUI. When the mobile robot platform moves, the map will simultaneously built by sensors and shown in GUI. The operator can modify the map generated by modification tool if there were some errors by comparing with real-time video from web camera. Figure 14(c) illustrated there was error in map because LRF cannot detect the black part on the wall and Figure 14(d) illustrated modified results. Figure 14(e) illustrates some errors because LRF just detected the feet part of bookshelf and Figure 14(f) was modified results by the operator using modification tool in GUI. The experimental results verified the effectiveness of the proposed method.
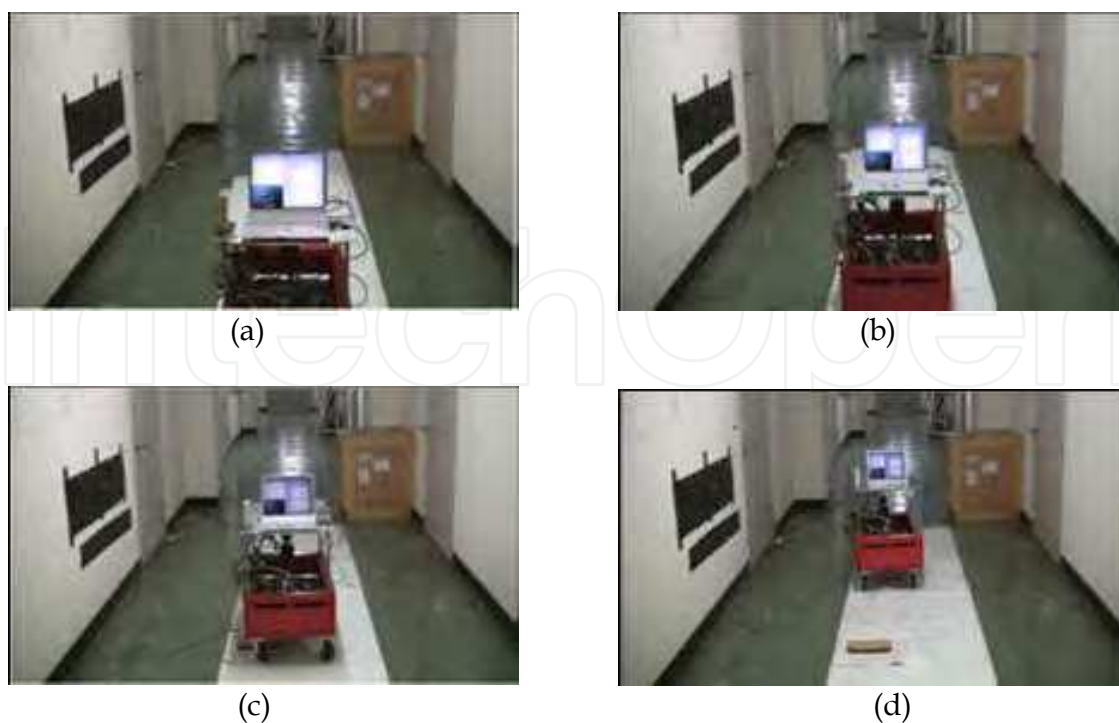

(a)   (b)

(c)   (d)

Fig. 13. Some images of experiments of mobile robot moving to build map.
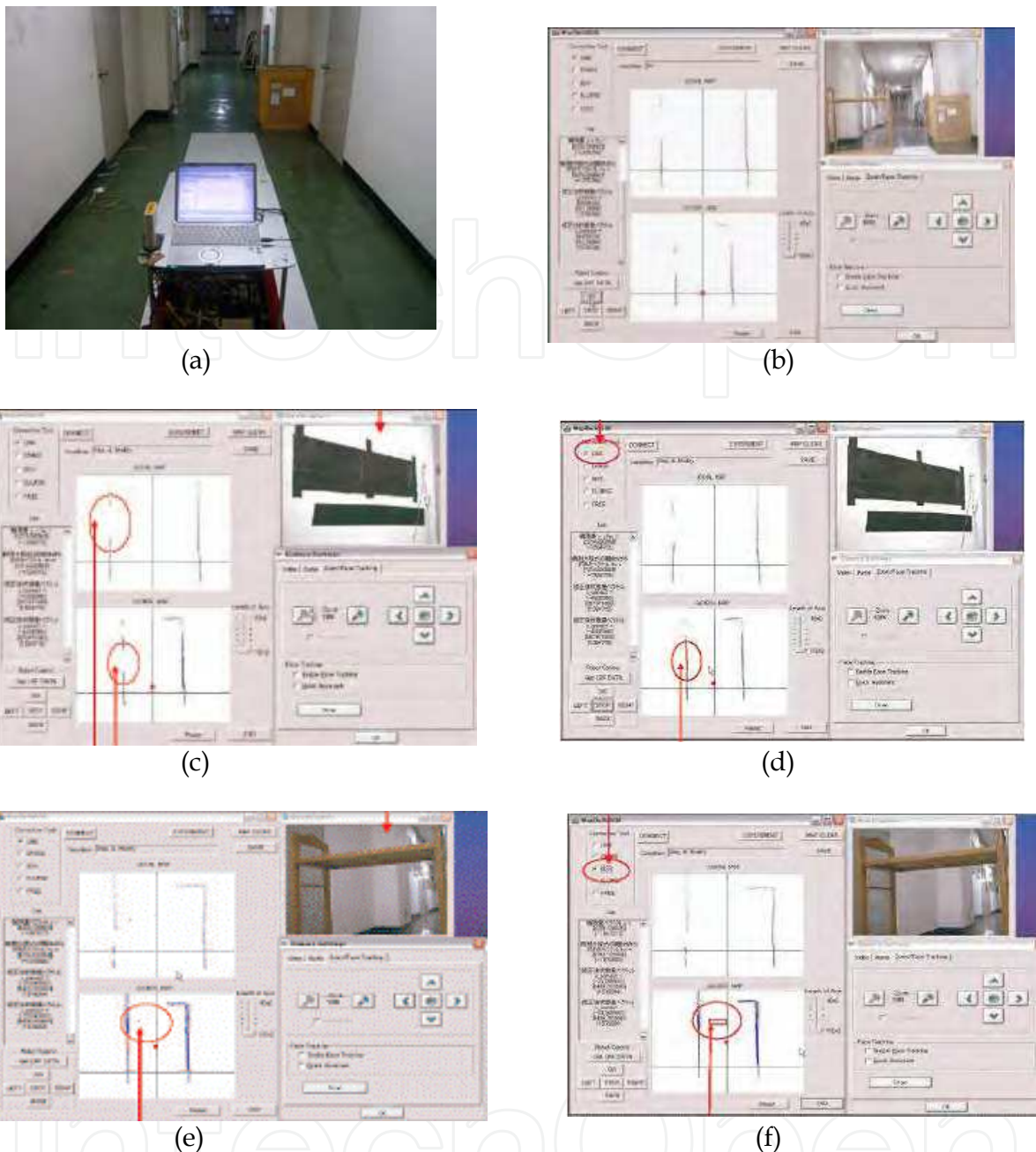
(a)

(b)

(c)

(d)

(e)

(f)

Fig. 14. Some images of experiments using interactive GUI to modify the map built by LRF.

7. Conclusion

Map building is a very important issue for mobile robot performing a task. It was difficult to generate an accurate map although many sensors or complicated system were used. This paper proposed a method of map building using interactive GUI for an indoor service mobile robot. The developed system enabled the operator to modify map built by LRF, compared with the real-time video from web camera if there was some errors in map because of misrecognition of sensors. We developed Extended Kalman Filter to improve the precision of the self-localization of mobile robot. The simulation and experimental results verified the effectiveness of the developed system. The current system just enabled the local

user to control; developing network function to allow the remote user to access system is the topic in the future.

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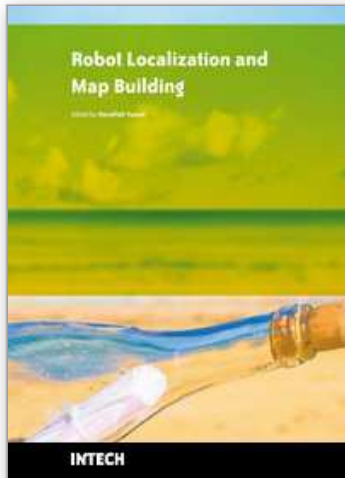
Robot Localization and Map Building

Edited by Hanafiah Yussof

Localization and mapping are the essence of successful navigation in mobile platform technology. Localization is a fundamental task in order to achieve high levels of autonomy in robot navigation and robustness in vehicle positioning. Robot localization and mapping is commonly related to cartography, combining science, technique and computation to build a trajectory map that reality can be modelled in ways that communicate spatial information effectively. This book describes comprehensive introduction, theories and applications related to localization, positioning and map building in mobile robot and autonomous vehicle platforms. It is organized in twenty seven chapters. Each chapter is rich with different degrees of details and approaches, supported by unique and actual resources that make it possible for readers to explore and learn the up to date knowledge in robot navigation technology. Understanding the theory and principles described in this book requires a multidisciplinary background of robotics, nonlinear system, sensor network, network engineering, computer science, physics, etc.

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