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Mobile robot localization based on omnicamera and laser range finder readings

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Abstract

In this paper a method of mobile robot localization in an unknown indoor environment is presented. The robot is equipped with a single omni-directional camera and laser range scanner. The data of the 2D scanner is used to detect walls in the robot environment. The images taken from omnicamera are used to detect vertical lines on the walls. The method of particle filters is used in order to determine the position of the robot. The method has been tested with the use of the mobile robot Elektron 1 in a real office environment.

Keywords: navigation, localization, mapping.

Lokalizacja robota mobilnego przy wykorzystaniu kamery dookólnej i dalmierza laserowego

Streszczenie

Określenie położenia jest jednym z podstawowych zadań robota mobilnego. Jako podstawowe źródło o przemieszczeniu pojazdu przyjmuje się wskazania odometrii. Dane te są obarczone błędami, które mogą mieć charakter systematyczny lub niesystematyczny. Wiarygodność wskazań odometrii maleje wraz z przebytą przez robota odległością. Dlatego w praktyce stosowane są dodatkowe metody określania położenia robota. W metodach tych oprócz informacji z czujników odometrycznych wykorzystywana jest informacja z sensorów obserwujących otoczenie. W opisywanym w tej pracy systemie wykorzystywane są dane pochodzące z dalmierza laserowego oraz kamery dookólnej. Na podstawie danych z dalmierza określane są krawędzie poziome wykrytych przeszkód, a na podstawie danych z kamery dookólnej krawędzie pionowe. Zastosowano metodę filtrów cząsteczkowych do określania położenia robota w globalnym układzie współrzędnych. W procesie generowania cząsteczek uwzględniana jest informacja o kierunkach głównych danego pomieszczenia. Informacja ta umożliwia zmniejszenie liczby cząsteczek. Agregacja informacji z różnych sensorów umożliwia dokonywanie lokalizacji w różnego typu pomieszczeniach.

Słowa kluczowe: nawigacja, lokalizacja, tworzenie mapy.

1. Introduction

Localization is one of the fundamental tasks of mobile robots. Until now, numerous localization methods have been proposed. The most widely used is odometry. It is inexpensive and provides a good short time accuracy but errors in determining the position of the robot increase proportionally with the distance travelled by the vehicle. Odometry errors can be systematic and non-systematic. In the papers [1, 2] the method called UBMmark test was described. The algorithm allows us the reduction of systematic errors of a mobile robot with a differential drive. It is very difficult to reduce non-systematic error. In order to update the position of the robot which has travelled for a prolonged period of time, additional methods should be used. These methods usually belong to one of two classes:

- *grid-map-based localization* [3, 4] is a technique in which a local map of an environment is built based on the sensor readings. The local map is then compared to a global map stored in the memory. Map-based positioning can be used to generate and to update the global map of the robot's environment, but the method is time consuming.
- Landmark-based localization [5, 6, 7] is a method in which the stationary features of an environment are the targets to be traced. The method consists of two stages: Firstly the landmarks are detected in the robot's environment then the position of the robot relative to the landmarks is determined. When the robot travels a short distance, new sensor indications are obtained and new positions of the landmarks relative to the robot are computed.

Usually the Kalman filter method is used to simultaneously estimate the robot position. In this method, the encoder readings are used as an input and sensors measurements as observations. Determining the displacement of the robot in relation to the landmarks allows us to update the position of the robot in the environment. In our approach the particle filter is used in order to determine the robot position within the environment. The main part of the algorithm is to detect and to match characteristic features of the environment. The decision as to which kind of landmarks should be used for localization depends on the robot's sensors. When sonars or laser range finders are used, then the walls, edges and discontinuities are the best features. In the method described in this paper, both omni-camera sensor and laser range finder are used as a source of information about the robot's environment.

2. Hardware

The robot *Elektron 1* is used in the experiments (see Fig. 1). It is equipped with SICK LMS 200 laser scanner and a panoramic camera.

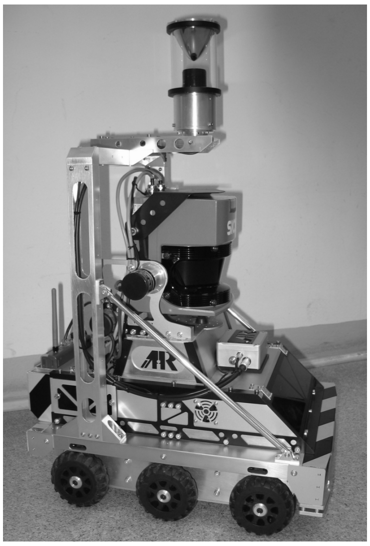


Fig. 1. Mobile robot Elektron1
Rys. 1. Robot mobilny Elektron

The omni-directional sensor is composed of a C-MOS colour camera pointed upwards at the vertex of the hyperbolical mirror. The optical axis of the camera and the optical axis of the mirror are aligned. Omnicamera sensors have been very popular over the last decade because they give 360 degree information about an environment. Based on the information obtained from the visual sensor, it is possible to built a 3D model of a scene [8]. The accuracy of the sensor depends on the distance between the optical axis and the detected object. Fig. 2 presents the interdependence between the distance to the obstacle and the error of measurement.

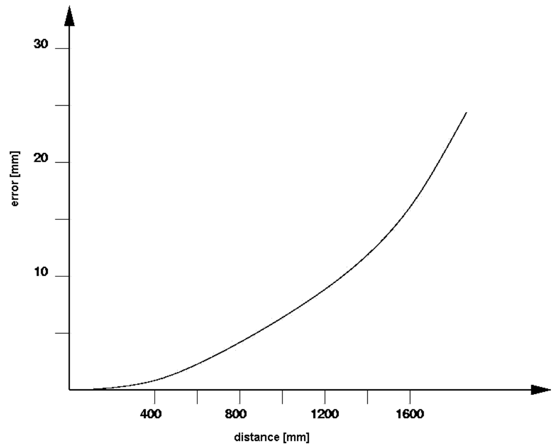


Fig. 2. Error of omnicamera measurements
Rys. 2. Zależność między odległością, a błędem wskazań kamery dookólnej

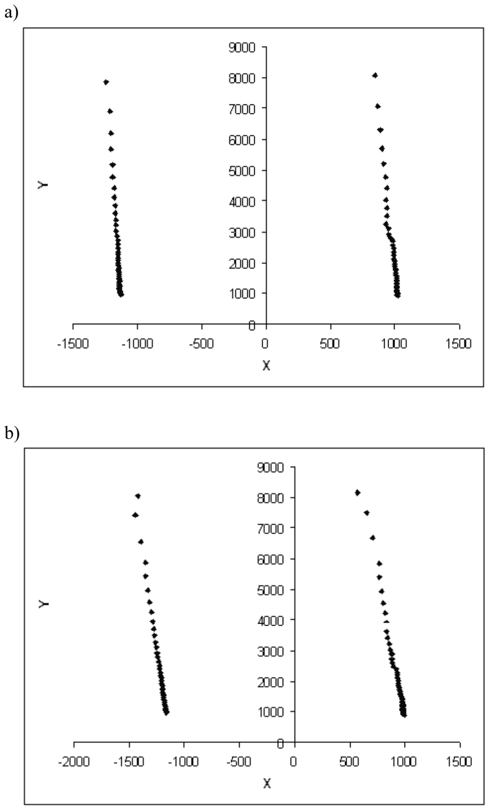


Fig. 3. Laser range finder readings: a) readings taken in the initial robot position, b) readings taken after 30 cm
Rys. 3. Wskazania dalmierza laserowego: a) początkowe położenie robota, b) odczyty otrzymane w odległości 30cm od położenia początkowego

The laser range scanner gives the set of pairs {(r_i, φ_i)}, where r_i denotes the distance to the nearest obstacles in the direction φ_i. The angular resolution of the sensors equals 1.0°. The laser finder is very accurate but it only provides 2D information about the robot's environment. In some situations 3D information is required. For example, when the robot moves along a very long corridor, it is impossible to determine the displacement of the robot based on laser range finder indications. Figs. 2a, 2b present the sensors reading taken in the corridor for two different position of the robot. The displacement of the robots equals 30cm. Figs. 2a and 2b are very similar. Figs. 3a,, 3b present the omnicamera images. The displacement of the robot equals 30cm. Fig. 3a differs from Fig. 3b.

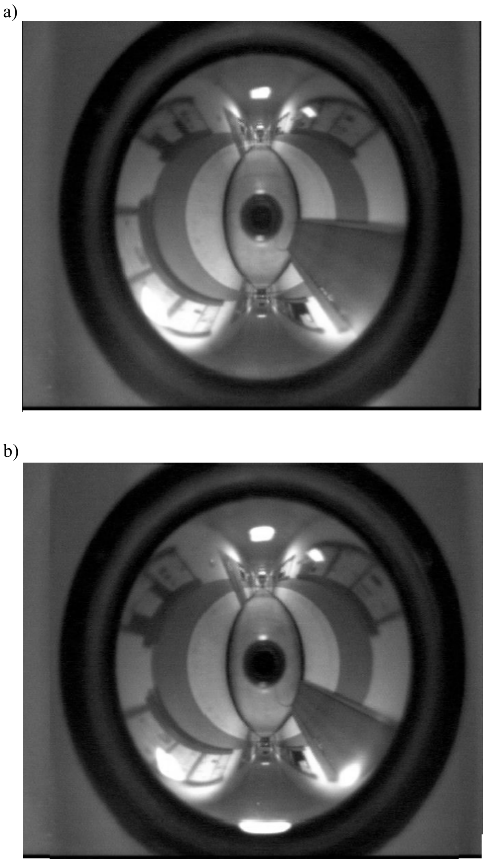


Fig. 4. Images taken from the omnicamera sensor: a) initial robot position, b) reading taken after 30 cm
Rys. 4. Obrazy otrzymane z kamery dookólnej: a) początkowe położenie robota, b) obraz otrzymany w odległości 30cm od położenia początkowego

3. Algorithm

The algorithm used for the mobile robot localization consists of the following steps:

- calibration of the omnicamera sensor, the method of omnicamera calibration is described in [9],
- data collection,
- detecting the natural landmarks of the environment,
- generating the set of particles,
- building (for each particle) 2D map of an environment based on the laser readings and images taken from the omnicamera,

updating the map of the environment

Based on the laser range finder reading, the position of the obstacles are calculated.

The coordinates of the obstacles can be computed based on following formulae:

$$\begin{aligned} x_i &= x_R + r_i \cos\ \varphi_i, \\ y_i &= y_R + r_i \sin\ \varphi_i. \end{aligned} \tag{3}$$

We can describe a line segment using the normal notation:

$$x \cos\alpha + y \sin\alpha = c, \tag{2}$$

where c is the distance from the origin to this line computed along a normal, and α is the orientation of the normal with respect to the

X axis. For points (x_i, y_i), which belong to the same line, the parameters α, *c* are the same. The Hough transform and regression method are used to determine the parameters (α, *c*) [10]. The error in determining the parameters depends on the length of the wall and the number of readings. When the robot moves along the corridor, the error of computing *c* does not increase 0.5cm, and the error of determining α does not increase 0.4^{o}.

The vertical edges of the environment look like radial segments in the images taken from the camera. The coordinates of the intersection of horizontal lines computed based on the laser range finder indications and vertical lines computed from images taken by the omnicamera, are natural features of the environment. Fig. 5 presents the idea behind the method.

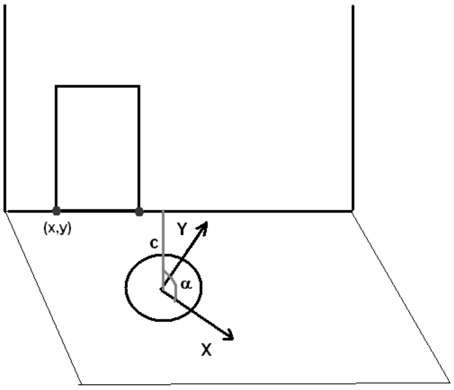


Fig. 5. The idea behind the method of the natural landmark detection
Rys. 5. Idea metody wykrywania naturalnych znaczników

The algorithm of computing the radial lines consists of the following steps:

- the Sobel method is applied in order to detect edges in the image[11],
- the image is thresholded [12],
- the radial lines are extracted from the image.

The radial lines are detected using the Hough transform. Then coordinates of intersection points (x_i,y_i) are computed.

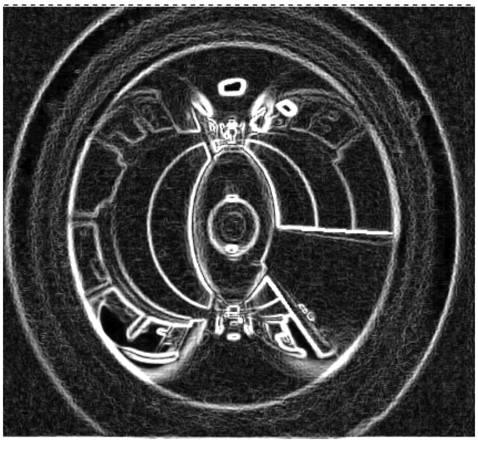
Fig. 6 presents the stages of radial line detection. Fig. 6a presents the Fig. 5a after edges extraction, Fig. 6a is a result of thresholding. Radial lines are presented in Fig. 6c.

Each pair (LRF data, omnicamera image) is described as a set of features:

$$\{(\alpha_1, c_1),\ldots,(\alpha_n, c_n),(x_1,y_1),\ldots(x_k,y_k)\},$$

where *n* is the number of horizontal lines, and *k* is the number of intersection points.

a)



b)

c)

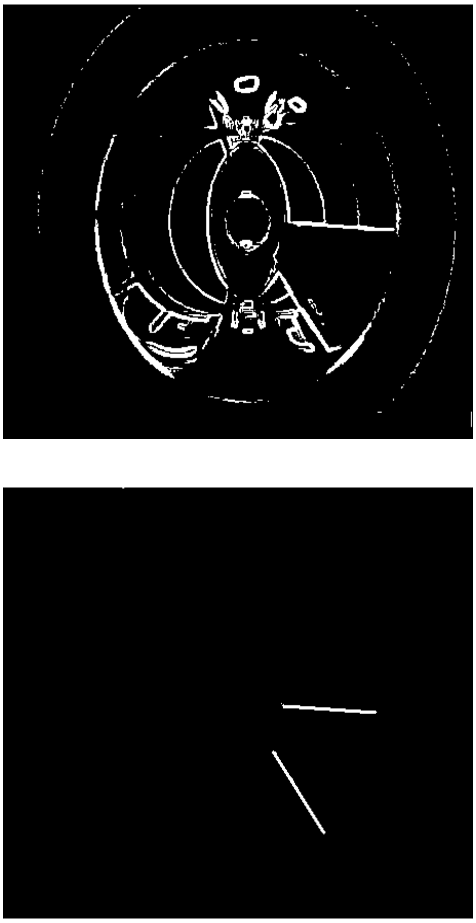


Fig. 6. Detection of the radial lines: a) Fig. 5 a) after the edges detection, b) thresholding c) radial lines
Rys. 6. Wykrywanie lini radialnych: a) krawędzie, Rys. 5a), b) progowanie, c) linie radialne

4. Mapping

Mapping techniques for mobile robots can be classified according to the form in which the environment is represented. One of the most popular is the occupancy grid map. This method allows us the rapid generation of a collision-free path for a mobile robot, but the accuracy of the map depends on the grid resolution. If a very precise map of the environment is required, then the method is computationally expensive and a huge amount of memory is necessary. Feature-based maps are attractive because they are concise and so are very useful during a localization process [12]. However, path planning based on this kind of map is time consuming. In our approach, a dual representation is used (both grid-based and feature-based). Each cell of the map contains the set of features – lines equations and coordinates of the points which represent the intersections between the vertical and the horizontal lines.

This kind of map allows for rapid generation of information about the main directions in the robot environment. This information is very useful during the process of self localization. Fig. 7 presents the histogram of the main directions of the environment which is presented in Fig. 4a. The histogram has been built for two different robot positions (green and red picks). The robot has changed its orientation of about 3^{o}.

The maximum value of the crosscorrelation function (Fig. 8) indicates the approximate difference in values between the orientations of the robot in two positions.

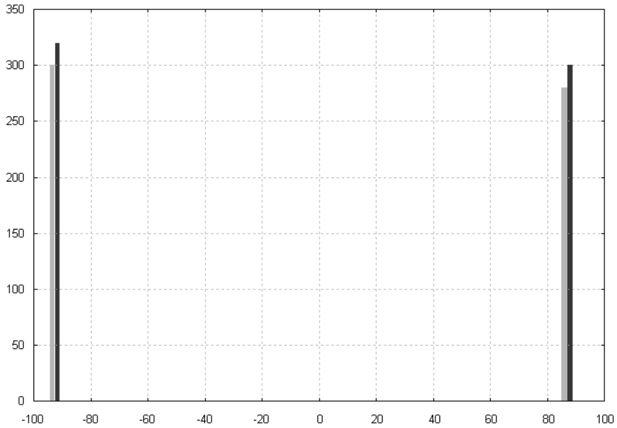


Fig. 7. Histogram of main directions
Rys. 7. Histogram kierunków głównych

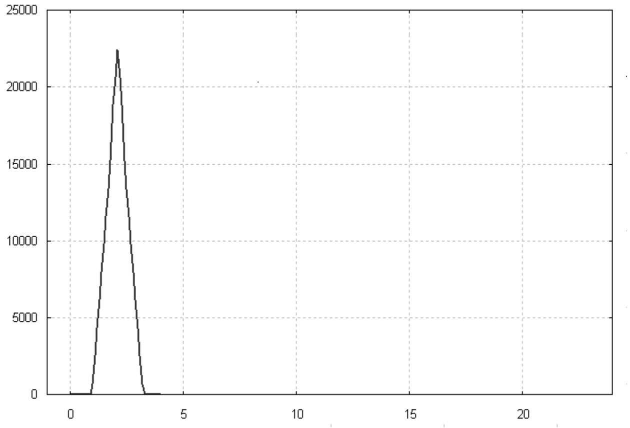


Fig. 8. The function of correlation
Rys. 8. Funkcja korelacji wzajemnej

5. Particle filters

The space of possible locations of the robot is represented by a set of *m* particles $S^t = \{ x^t_i, w^t_i \}$ $i=1,..,m$. Each sample x^t_i represents a possible robot location. The weight w^t_i is attached to each particle.

The algorithm [12] consists of the following steps:

- The values $\{ x^t_i \}$ represent the set of possible positions of the robot and their uncertainty. The weights w^t_i are non-negative values called importance factors and they sum up to one. These factors indicate how important each sample is.
- In the next step the new value x^{t+1}_i is computed. The particles are iteratively propagated using the control input (motion model).
- On the basis of the measurement model, a weight $\underline{w}^{t+1}_i$ is attached to each particle. The value $\underline{w}^{t+1}_i$ is described by equation:

$$\underline{w}^{ji}{}_{t+1} = \prod_{s=1}^{n} \frac{1}{\sigma^2_{p_s} \sqrt{2\pi}} e^{\frac{-\delta {p_s}^2}{\sigma^2_{p_s}}}, \tag{3}$$

where $-\delta p_s$ is the difference between predicted and measured values of the parameter p_s, and $\sigma^2_{p_s}$ is the variance of the parameter p_s.

- The weights are normalized according to the formulae:

$$w^i_{t+1} = \frac{\underline{w}^i_{t+1}}{\sum\limits_{i=1,N} \underline{w}^i_{t+1}} . \tag{4}$$

- The particles which have the maximum values of $w^{t+1}{}_i$ are multiplied, and particles with the value of $w^{t+1}{}_i$ below some threshold are reduced.

The number of particles depends on the uncertainty of odometry. In the case of the mobile robot *Elektron*1, the error of determining the orientation of the robot surpasses 20°. A large number of particles has to be used during the localization process. In order to improve the odometry, the information about the main directions is taken into account during the propagation of the particles. The error in determining the orientation does not surpass 3°. This approach allows us a reduction in the number of the particles.

6. Conclusions and future works

In this paper, I have presented an improved approach to the mobile robot localization using particle filters. The method maintains feature maps and grid maps to represent the structure of the environment. The method allows the robot to select the model of the environment. It is demonstrated that the presented technique allows the robot to localize within different types of environment. The approach is much better than the traditional approach that uses only features or grid maps.

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