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Occupancy grids building by sonar and mobile robot

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Abstract

In this paper, a modified method for occupancy grid map building by a moving mobile robot and a scanning ultrasonic range-finder is proposed. The map building process consists of two phases: (1) gleaning of information from environment, and (2) sonar data processing. For sonar data processing the proposed modified method combines: (1) statistical approach for probability sonar model building; and (2) application of fuzzy logic theory for sonar data fusion. It is experimentally shown that, in some applications, the proposed modified method has advantages over other well-known methods.

Introduction

The performance of an autonomous mobile robot for real-world modeling as well as for navigating in an unknown or partially known environment depends strongly on its perception capabilities. The system requires gleaning of a large amount of sensory information to integrate it into a proper representation of the environment. Due to its efficiency, a widely used representation is a bitmap of the free and the occupied space[6],

[7], [13]. It is based on the use of a two-dimensional tessellation called occupancy grid (OG), and was first introduced by Moravec and Elfes[14]. In principle, OGs store qualitative information about which areas of the robot's surroundings are (completely) empty, and which areas are (even partially) occupied by obstacles[7], [14]. Occupancy maps have been built using laser range-finders[8], stereo vision[5], and ultrasonic range-finders[1], [6], [9]. Laser range-finders have high angular resolution, but they depend on the lighting and brightness of surfaces[11], on smoke, mist, etc. Moreover, they are more expensive than most other spatial sensors. The stereo vision also depends on the lighting, smoke, mist, etc. As is discussed in[5], stereo vision mapping is very sensitive to errors, as the process of collapsing the data from 3D to 2D encourages errors in the form of "spikes" that are propagated into the map. In[5], the authors used the stereo vision for constructing occupancy grid maps. The paper describes a working vision-based mobile robot that navigates and autonomously explores its environment while building occupancy grid maps of the environment. Several example results were given. One serious problem that remains unsolved in this mapping and navigation implementation is the problem of seeing over, under or past objects. Certain objects are very difficult to see for the stereo vision, due to the large occlusions involved[5]. Another problem that remains is the localization problem. Regardless of the quality of the maps, their utility is limited because the robot cannot reuse them from power-up to power-up, and also as odometry drift accumulates, old map data becomes inaccurate[5].

Ultrasonic range-finders, briefly referred as sonars[10], are common in mobile robot navigation due to their simplicity of operation[7], robustness, and low price. Ultrasonic range-finders don't depend on the lighting and brightness of surfaces, even if they are influenced by the matter in which the objects are made; they don't depend on smoke, and they don't need cumbersome equipment. But, on the other hand, these devices are prone to several measuring errors due to various phenomena (e.g.,multiple reflections, wide radiation cone, low angular resolution[3], [7], [10]). Ultrasonic range-finders provide relative distances between them and surrounding obstacles located within their angular detection range, also called "sonar detection cone". The time elapsed between the wave transmission and the reception of its echo allows computing the range reading r. This means that an obstacle may be located somewhere on the arc of radius r within the angular detection range. The angular detection range depends on the radiation directivity of a sonar transducer[6], [13] as well as on the characteristics of the interface electronic blocks: working frequency, amplification of the received signal, beam width of the amplifier, trigger level, etc. The most common mobile robotics ultrasonic range-finders, reported in[3], [6], [10], [19], have angular detection range $(15–35)^\circ$. During the last years, several companies[17], [18], [20] suggested ultrasonic ranging systems with improved (but still limited) angular resolution, with an angular detection range (5–9)°. However, the prices of these devices are comparatively high[17], [18], [20].

Nowadays many efforts in mobile robotics are directed to develop some kind of "uncertainty calculi" techniques for recovering spatial information from obtained sonar data. In the literature, three different uncertainty calculi techniques for building occupancy grids of an unknown environment based on sensory information provided by ultrasonic range-finders are discussed[1], [6], [7], [13]. These techniques are based on Bayesian theory (probabilistic approach)[1], Dempster–Shafer theory of evidence (evidence theoretic approach)[7], [13], and fuzzy set theory (fuzzy logic, or possibilistic approach)[6], [7], [13]. The probabilistic approach is the most widely found in mobile robotic literature[1], [4], [8], [9], [12]. The Bayesian method rules the greatest part of the work related to the probabilistic sensor fusion in building OGs[7]. This attraction stems from the property of the Bayes' updating rule which facilitates recursive and incremental schemes[7]. However, in order to avoid huge calculation processes one must assume that the cell states are independent. It has been observed[6] that this assumption may induce large errors in the presence of even a slight degree of dependence between the random variables—this is exactly the case for map building, since the occupied cells are not evenly distributed, but concentrated in clusters (obstacles). Moreover, the prior probabilities needed to initialize the field are typically estimated with the maximum entropy assumption, namely by regarding emptiness and occupancy as equiprobable[6]. As a consequence, the convergence of the Bayesian updating procedure towards an acceptable characterization of the occupancy grid requires a large number of measures[6]. The articles[9] and[12] describe algorithms for acquiring occupancy grid maps with mobile robots, which rely on the probabilistic approach. These algorithms employ the expectation maximization (EM) algorithm[9], [12] for searching maps that maximize the likelihood of the sensor measurements. The approach presented in[9] relies on a statistical formulation of the mapping problem using forward models. Experimental results are presented, which are obtained using a RWI B21 robot equipped with 24 sonar sensors. The disadvantages of this approach are an apparent increased sensitivity to changes in the environment, and a need to go through the data multiple times, which prohibits its real-time application[9]. Moreover, in[16], it is pointed out that the EM-based techniques suffer from a high computational complexity. Besides, EM is not guaranteed to converge to a global optimum[16]. In[4], the author describes and compares various probabilistic techniques, as they are presently being applied to a vast array of mobile robot mapping problems. The history of robotic mapping is also described, along with an extensive list of open research problems.

The well known techniques for OGs building were experimented and comparisons were performed in[7], [13]. It was shown that the fuzzy logic approach has the best performance, especially in the case of unstructured environments[7], [13]. The experimental results indicated that the method based on fuzzy logic is more robust with respect to the occurrence of false reflections in the measuring process[6]. Also it was shown that stochastic techniques based on Bayesian updating are very sensitive to the occurrence of outliers in the measuring process[6]. In[16], the authors integrated topological and grid-based representations for the purpose of constructing globally consistent metric models of large, real world environments. Using their approach, a sonar-equipped mobile robot is able to construct detailed models of large environments[16]. The approach proposed in[16] includes an off-line algorithm for constructing a global gridmap. The algorithm is based on the fuzzy logic approach for OGs building, given in[6].

In this work, a modified method for occupancy grid map building by mobile robot and scanning ultrasonic range-finder is proposed. The map building process consists of two phases: (1) gleaning of information from environment, and (2) sonar data processing. The sonar data processing combines: (1) statistical approach for probability sonar model building; and (2) application of fuzzy logic theory for sonar data fusion. The proposed method is a modification of the original method, presented in[6]. It is experimentally shown that, in some applications, the proposed modified method has advantages over other well-known methods. Employing the proposed method in this paper as well as the well-known method[6], we obtained maps of two experimental laboratory environments. The experimental results obtained showed that in the presence of multiple reflections, the method proposed in this paper produced maps in which the contours of the objects were more even, and the wrong measurement results due to multiple reflections were rejected better.

Section snippets

Gleaning of information from environment—experimental setup

Both the proposed modified method and original method[6] were used to built OGs of two office like environments, shown in Fig. 1(a, b). The experimental real range data were gathered by the mobile mini-robot *LAMOR*[15], developed in the *Institute of Control and System Research, Bulgarian Academy of Science*. The mobile robot is equipped with scanning sonar based on *POLAROID* ranging modules[19]. The home angular position of the sonar's transducer is 0°, i.e.,the sonar's transducer is directed …

Probability model of the sonar

The ultrasonic sensor detects the closest reflecting surface inside its angular detection range, thereby indicating the presence of an empty space up to a certain distance. A single reading r provides the information that one or more obstacles are located somewhere along the arc of circumference of radius r.

The probability model of the sonar includes: (1) probability directional diagram $P(\theta)$ of the sonar; and (2) probability estimation of the sonar measurements …

Short description of the original method [6]

As is explained in Section 3.2.1, the basic idea of the original method [6], is that the empty and the occupied space are defined as two fuzzy sets ε and o over the universal set U (the environment), discretized in square cells of side d. Their membership functions $\mu_\varepsilon(C)$ and $\mu_o(C)$ quantify the degree of belief that the cell $C \in U$ is empty or occupied, respectively:

$$\begin{array}{l} \mu_{\varepsilon_i^k}(\rho,\vartheta) = f_\varepsilon\left(\rho, r_i^k\right) m(\vartheta)\, \nu(\rho) \\ \mu_{o_i^k}(\rho,\vartheta) = f_o\left(\rho, r_i^k\right) m(\vartheta)\, \nu(\rho) \end{array} \left| \begin{array}{l} f_\varepsilon(\rho, r) = k_\varepsilon, \quad \text{if } (0 \le \rho < r - \Delta r); \\ f_\varepsilon(\rho, r) = k_\varepsilon \left(\frac{r-\rho}{\Delta r}\right)^2, \quad \text{if } (r - \Delta r \le \rho < r); \,|\, f_o \cdots \\ f_\varepsilon(\rho, r) = 0, \quad \text{if } (\rho \ge r) \end{array} \right.$$

Integrated occupancy grid map

In the maps of the global crisp sets E representing the empty cells shown in Fig.9(b, d), note the gray areas extending beyond the smooth walls C and D. These are lot of cells, which are registered in the maps as “empty” due to false reflections occurring for large angles of incidence. Nevertheless, in the maps of occupied cells, the proposed map building algorithm was able to reconstruct accurately the profile of the walls as well as the profile of the object E, by incorporating the range …

Conclusions

A modified method for environment map building by mobile robot and scanning ultrasonic range-finder is proposed. The map building process consists of two phases: (1) gleaning of information from the environment, and (2) sonar data processing. The proposed method is a modification of the original method, presented in [6]. For sonar data processing, the proposed modified method combines: (1) statistical approach for probability sonar model building; and (2) application of fuzzy logic theory for …

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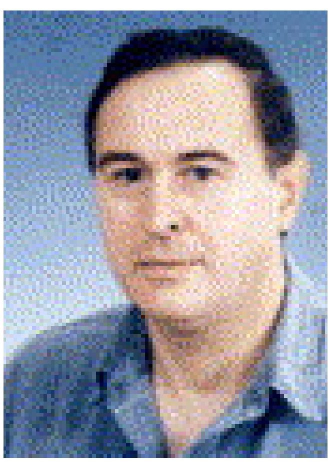

Ch. Roumenin was born in 1949 in Sofia. In 1975 he graduated from the Physical Department of Moscow State University (Russia). In 1977 he acquired his Ph.D. degree on galvanomagnetic properties of InSb and in 1995 his full Doctor of Science degree on magnetic field sensors and microsystems and their applications. He is currently a professor of sensors and sensor electronics at the Institute of Control and System Research, Bulgarian Academy of Sciences. Since 1999 he was Director of the ICSR. In 2004 Ch. Roumenin was elected as Corresponding Member of the Bulgarian Academy of Sciences. Dr. Roumenin has published over 260 papers, 3 books and over 65 patents on novel sensors and microsystems. He is distinguished by the title Emeritus Inventor of Bulgaria and his name was entered in the Golden Book of Bulgarian Inventors in 1977. Ch.S. Roumenin is a member of the Eurosensors Intern. Steering Committee and the Editorial Board of Sensors and Actuators Journal.

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