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A novel mobile robot localization approach based on topological maps using classification with reject option in omnidirectional images

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ABSTRACT

Mobile robot localization, which allows a robot to identify its position, is one of main challenges in the field of Robotics. In this work, we provide an evaluation of consolidated feature extractions and machine learning techniques from omnidirectional images focusing on topological map and localization tasks. The main contributions of this work are a novel method for localization via classification with reject option using omnidirectional images, as well as two novel omnidirectional image data sets. The localization system was analyzed in both virtual and real environments. Based on the experiments performed, the Minimal Learning Machine with Nearest Neighbors classifier and Local Binary Patterns feature extraction proved to be the best combination for mobile robot localization with accuracy of 96.7% and an Fscore of 96.6%.

1. Introduction

Interest in autonomous mobile robots is increasing along with the advancements in technology being made. Mobile robots have been widely applied to military and civilian tasks. In Bengochea-Guevara, Conesa-Muñoz, Andújar, and Ribeiro (2016), the authors presented an example of an autonomous robot in precision agriculture. Song, Gao, Ding, Deng, and Chao (2015) used a mobile robot to identify terrain parameters. Miksik, Petyovsky, Zalud, and Jura (2011) presented an unmanned ground vehicle that can be used for nuclear, chemical and biological contamination measurements among other applications.

Mobile robot mapping and localization methods can be grouped into two central paradigms (Enrico, Groen, Arai, Dillmann, & Stenz, 2000): (i) geometric, such as Arbeiter, Bormann, Fischer, Hägele, and Verl (2012); Nagla, Uddin, and Singh (2012); Zhang, Liu, and Tan (2015), and (ii) topological, such as Chin, Loo, Seera, Kubota, and Toda (2016); Dawood and Loo (2015); Gerstmayr-Hillen et al. (2013); Hafez and Loo (2015). Geometric maps represent the total navigation space in a global coordinate system. Instead of focusing on stiff geometric information, topological methods represent the environment as a graph. The vertexes are locations in the environment and are connected by arches, if there is a path between them Rady (2016); Wu, hui Tian, Li, yu Zhou, and Duan (2014). Topological maps are useful for mobile robot localization tasks. These kinds of maps are compact and simple, require less computer memory, and consequently speed up robot navigation processes (Cheng, Chen, & Liu, 2015). Other methods are a combination of both geometric and topological methods. Good examples of this hybrid approach are presented in Rady (2016); Wu et al. (2014).

In the outdoor environment, navigation systems such as the Global Positioning System (GPS) provide precise positions and can be applied in mobile robot localization. However, in an indoor environment it is difficult for GPS to supply accurate positioning information. In the latter environments, different positioning methods have been proposed, such as the ultrasound, Bluetooth, Wi-Fi, image recognition and inertial navigation (Song, Jiang, & Huang, 2011; Xu, Chen, Xu, & Ji, 2015; Zhu, Yang, Wu, & Liu, 2014). Yayan, Yucel, and Yazıcı (2015) presented an indoor positioning system that uses ultrasonic signals and calculates the position of the mobile robot. Nevertheless, this type of positioning system suffers from small noise sources such as jangling metal objects. A method for mobile robot localization in a partially unknown indoor environment which merge ultrasonic sensors with a laser range finder (LRF) was proposed in Ko and Kuc (2015). Nevertheless, the usage of expensive sensors for the identification is the main drawback of the LRF. Song, Li, Tang, and Zhang (2016) presented a positioning

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system with Radio-Frequency Identification (RFID). However, the system needs a complex infrastructure in the environment.

Mobile robot vision-based navigation has been extensively studied in computational vision and control and automation engineering (Wang, Cai, Yi, & Li, 2012). The images captured by a vision-based system need to be described and compared to carry out mapping and localization tasks. The description technique used can be based on global descriptors, on local features, on Bag-Of-Words (BoW) schemes, see Li, Dong, Xiao, and Zhou (2016), or based on combined approaches (Garcia-Fidalgo & Ortiz, 2015). Woo, Lim, and Lee (2010) proposed a system that combines global with local features to identify pedestrians and vehicles. Aldana-Murillo, Hayet, and Becerra (2015) used local descriptors in the problem of appearance-based localization.

Global descriptors are usually effective to solve the computational needs during mapping and localization tasks. However, solutions based on global representation (different fields of knowledge) suffer from problems such as occlusions or camera rotations. These issues have been widely discussed with the current advancement of local features (Garcia-Fidalgo & Ortiz, 2015). Khan, Ahmed, and Khan (2013) presented a solution for a surveillance problem using image moments and artificial neural networks. Boroş, Roşca, and Iftene (2010) applied Scale Invariant Feature Transform (SIFT) to solve the problem of global topological localization for indoor environments. In Zhang and Hua (2015), Local Binary Patterns (LBP) were used to face the detection task. Raheja, Kumar, and Chaudhary (2013) presented a system to detect fabric defects using Gray Level Co-occurrence Matrix (GLCM). These methods are effective in scene recognition due to their properties of building new features that are powerfully related to the output class.

Machine learning methods have been widely applied along with computer vision techniques into mobile robot navigation systems due their effective capacity of learning complex patterns and making decisions based on data (Yang, Shao, Zheng, Wang, & Song, 2011a). Charalampous, Kostavelis, and Gasteratos (2015) presented a local path planning method, incorporating the support vector machines (SVM) algorithm. Caron, Filliat, and Gepperth (2015) used a feed-forward neural network along with a RGB-D camera for object recognition. In Kasat and Thepade (2016), an image classification approach was proposed using Bayes classifier.

Some applications require high performance (high accuracy and short processing time) through convectional cameras. Omnidirectional vision systems have been widely used because they increase the amount of information available. A system with a panoramic view provides a 360° image, that may be necessary, for example, when the task performed by the robot needs to have constant visual information of objects in different places (Scaramuzza, 2014). Kim and Kweon (2013) presented a paradigm of a global localization method using an omnidirectional camera. In Maohai, Han, Lining, and Zesu (2013), a topological navigation strategy for an omnidirectional mobile robot using an omnidirectional camera was described.

The aim of this work is to provide an evaluation of consolidated feature extractions and machine learning techniques in omnidirectional images focusing on a topological map and mobile robot localization tasks. In this work, a new and robust method for localization via classification with option using omnidirectional images was developed and analyzed. Initially, the navigation system was analyzed with images generated from a virtual environment. Posteriorly, the same perception module based on a vision sensor was used in a real environment with an omnidirectional camera. The developed systems were able to recognize the navigable area of the environments by processing the input data and to classify them into states which represent the current robot context. These capabilities allowed the robots to determine their localization on a topological map and also to autonomously navigate through the environment, reaching the desired destination. Results show that the Minimal Learning Machine with Nearest Neighbors (MLM-NN) is a promising classifier for the analytical task. In addition, the experiments demonstrated that LBP was the best feature extraction technique for this task.

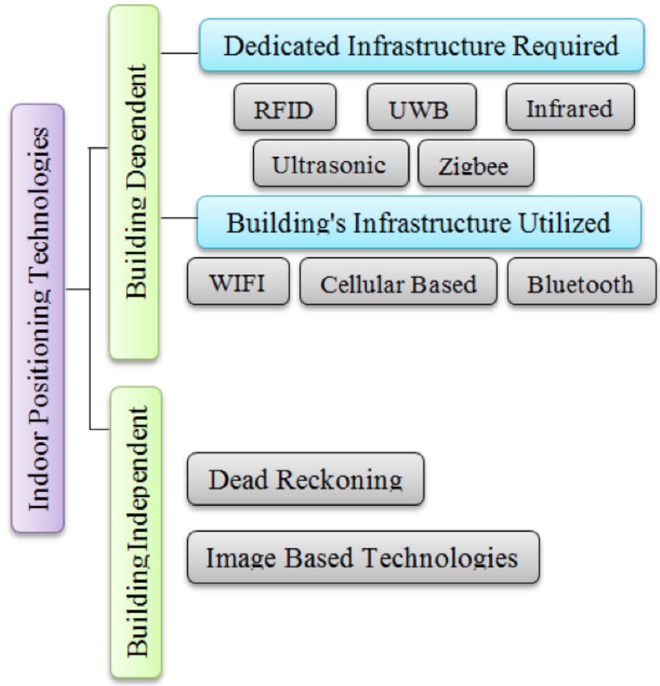

Fig. 1. Categorization of indoor positioning technologies (Alarifi et al., 2016).

2. Related work

Localization requires a robot to estimate its position in the environment. This is a basic ability for any navigation task (Castellanos & Tardos, 2012). Thus, the localization system must acquire the largest amount of information concerning the environment as possible. There are numerous types of sensors used in mobile robotics for this task and among them are technologies based on ultrasound, on laser or based on computer vision (Deak, Curran, & Condell, 2012). Alarifi et al. (2016) classified indoor positioning technologies according to the infrastructure of the system that uses them, see Fig 1. Table 1 compares the advantages and disadvantages of these technologies and indicates some studies related to these technologies. There are numerous advantages of using a localization method based on computer vision. They are easily scalable without significant increase of costs, and they do not demand changing the environment (Mautz & Tilch, 2011).

Garcia-Fidalgo and Ortiz (2015) reviewed several approaches with regard to topological mapping and localization by visual means. The authors classify these approaches into global descriptors, local features, or Bag-Of-Words (BoW). Table 2 presents the advantages and disadvantages of each of these approaches and some applications. As shown in Table 2, there are several contributions for the use of computer vision in navigation and robot localization. Computer vision is used in the proposed approach, This work use this approach, however with two contributions, one from the scientific point of view and the other from the technological point of view.

Decision support methods have evolved to reproduce decisions similar to those made by humans. However, these methods still have errors. Thus, paradigms, which provide a more viable alternative, have been developed when the confidence in the decision is low (Gamelas Sousa, Rocha Neto, Cardoso, & Barreto, 2015). Faced