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Gradient-driven parking navigation using a continuous information potential field based on wireless sensor network

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ABSTRACT

Wireless sensor networks can support building and transportation system automation in numerous ways. An emerging application is to guide drivers to promptly locate vacant parking spaces in large parking structures during peak hours. This paper proposes efficient parking navigation via a continuous information potential field and gradient ascent method. Our theoretical analysis proves the convergence of a proposed algorithm and efficient convergence during the first and second steps of the algorithm to effectively prevent parking navigation from a gridlock situation. The empirical study demonstrates that the proposed algorithm performs more efficiently than existing algorithms.

1. Introduction

1.1. Motivation

Wireless sensor networks (WSNs) can assist large building and transportation system automation in numerous ways [4]. An appealing application of WSNs is to guide drivers to promptly locate vacant parking spaces in large parking structures. This cannot be accomplished with the aid of traditional global positioning systems (GPS) because most large parking facilities are located inside buildings where GPS signals are not applicable, such as airport parking lots. Even for outdoor parking structures, WSNs-based solutions are better because they are more accurate and efficient, such as parking lots surrounding large shopping malls. In addition, it does not require communication with satellites or consume users' valuable smart phone data, jeopardizing monthly data plan limits. Studies [17,30] perform localization based on the offline analysis of data collected from sensor networks.

An existing study [33] can accurately guide drivers to vacant parking spaces by constructing the virtual information field depended on harmonic functions. However, this method is restrictively constrained by two computationally expensive mathematical boundary conditions. Due to the limited computing power of embedded systems, users experience a long waiting time while driving. In addition, the approach frequently guides multiple drivers to the same vacant parking space. Unacceptable long delays renders the approach unrealistic due to high computational complexity and competition for the

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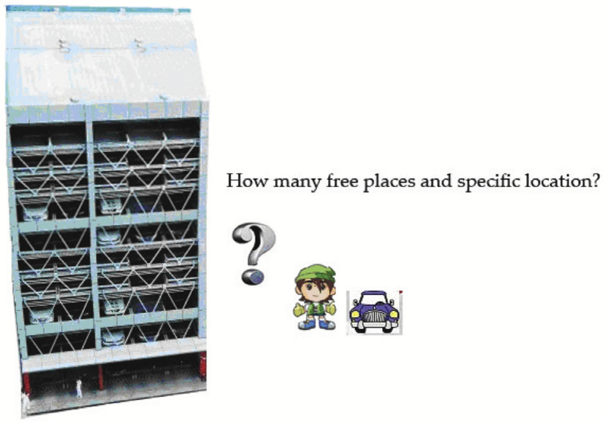

Fig. 1. Real Parkinglot scenario.

same parking spaces. In the following parts, we will propose a lower cost and convenient method that can overcomes the current difficulties with the novel mind from the brand new perspective. Simultaneously, we also discuss the fulfilling details of this new plan. In the Fig. 1, it vividly expresses the real scenario of navigation process.

1.2. Main contributions and novelty

We propose a novel approach to address the issues. To reduce the computational complexity, we relax the constraints by removing the Dirichlet [22] and Neumann boundary [28] conditions. These relaxations may reduce the accuracy of the detection for guidance. However, drivers may not need additional guidance after vacant visible parking spaces are found nearby. These guidance may alleviate competition by guiding drivers to an area with more vacant parking spaces. Our idea is inspired by the theory of magnetic field [3,19], where the object in the field is always attracted by the location with the highest value. Our article construct a gradient field in the parking space structures; our approach will guide vehicles toward the highest value location along the gradient ascent path. Note that the well-studied robotic navigation algorithms [2] cannot be directly applied here since the latter case does not consider human guidance and has static destinations that are known in advance. As a basic physical concept, the information field is introduced in this paper. Sensor nodes are responsible for monitoring the availability of parking spaces. In real scenarios, the information for empty or used parking spaces is dynamically and efficiently collected to enable us to construct an entire virtual information field that reflects parking space information based on this physical concept (information field). This information field is constructed by the heat diffusion equation.

To make our approach feasible, it is also depended on relevant supporting hardware. With any sentient organism [23], a WSNs relies on sensory data from the real world. Sensory data are obtained from multiple sensors of different modalities in distributed locations. The sensors in our proposed WSNs parking navigation system can be classified into two types, namely, static nodes and mobile nodes. Static nodes are sensors that persistently monitor parking lots to provide information about vacant parking spaces. They communicate with surrounding static nodes and human guidance mobile nodes within their communication ranges. Mobile nodes are sensors that are attached to vehicles to query nearby static nodes and utilize the returned information to guide vehicles to their desired destination. Since the situations of parking spaces change over time, real-time tracking may induce heavy communication overheads within the sensor network. Therefore, an effective method that notifies the changes of parking spaces among the static nodes and enables mobile nodes to collect the latest information with minimum communication costs.

The remainder of the paper is organized as follows: Related studies are discussed in Section 2. In Section 3, after an introduction of information diffusion and heat equation, we propose a surface fitting model and establish a global information field. Section 4 presents a local information field reconstructed by Poisson equation, followed by numerical studies and simulations in Section 5. Conclusions are presented in Section 6.

2. Related works

Navigation is a rudimentary problem in many research areas, especially in robotics. Borenstein et al. [31] reported that the general mobile robot navigation task can be decomposed as an answer to three fundamental questions, namely, positioning (where am I), targeting (where am I going) and routing (how should I get there). A landmark-based approach for mobile robot navigation was developed [32], in which landmarks are deployed to provide accurate obstacle information. However, this scheme is vulnerable in dynamic environments because the changes are hard to capture in real time. An artificial potential field [32] was introduced as a possible solution for this issue. To improve the adaptability to dynamic environments, a