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Enhancing the performance of a ubiquitous location-aware service system using a fuzzy collaborative problem solving strategy ☆

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ABSTRACT

Location-aware services (LAS) are special context-aware services that recommend suitable services to a user based on the user's location. However, considerable uncertainty exists when detecting a user's location. Previous studies have rarely discussed such uncertainty, or emphasized the timeliness and efficiency of such systems. Therefore, a fuzzy collaborative problem solving strategy was used to enhance the performance of a ubiquitous LAS system, measured according to the timeliness of a service and the efficiency of the recommendation process. The uncertainty of detecting a user's location using GPS is first considered by modeling the location and speed of the user with fuzzy numbers. After considering these uncertain parameters, a fuzzy mixed-integer programming problem is formulated to determine the timely service location and path for each user. However, the fuzzy mixed-integer programming problem is not easy to solve. Therefore, a fuzzy collaborative problem solving strategy is used to decompose the fuzzy mixed-integer programming problem into smaller pieces that can be handled by separate processing modules. The most favorable path to a user also leads the user to a region with multiple service locations instead of a single service, to maximize total timeliness. To elaborate the effectiveness of the proposed methodology, an experiment was conducted in downtown Taichung City, Taiwan. Based on the experimental results, the proposed methodology was able to be used to determine a timely service location for a specific user, as revealed by the reduced average waiting time. The proposed methodology also reduced the time necessary to find a timely location and path, which contributed to its enhanced efficiency.

1. Introduction

Location-aware services (LASs), or location-based services, are a hot topic in ambient intelligence. A LAS is a special context-aware service that recommends suitable services to a user based on the user's location (Dey, 2001). The primary research fields of LAS include mobile commerce, human–computer interface, remote detection, and ubiquitous computing. Location-aware photo annotation, Google Maps,, emergency escape route guiding systems, and mobile marketing are examples of LASs.

Krevl and Ciglarič (2006) built a design framework for a LAS. There are three layers in the framework, i.e. the client layer, the application/server layer, and the database layer. Park et al. posited that providing LASs is difficult because of latency, limited display, and intermittent connectivity to the backend database (Park, Hong, & Cho, 2007). However, new types of smartphones are equipped with digital compass or tilt sensors that enable orientation-aware interaction (Simon, Frohlich, & Grechenig, 2008). Espeter and Raubal (2009) recently argued that personalization is one of the most essential developments in LASs; however, how to simultaneously support multiple users requires further study. Raper et al. (2007) listed substantial relevant research topics pertaining to LASs. The analysis of trajectory data is of critical importance to decision-making in LASs (Guo, Liu, & Jin, 2010). Duckham, Winter, and Robinson (2010) proposed the core landmark navigation model for generating navigation instructions that refer to landmarks based on semantic categories. Gulati (2013) stated that the technology stack of a LAS is composed of a Web services programming language, HTML standards, a database, a geoinformation service, and an open Apps space. Lin and Chen (2013) modeled the inaccuracy of positioning a user using a fuzzy number (see Fig. 1).

In sum, existing LASs have the following problems:

1. A systematic procedure for designing a practicable LAS is lacking.

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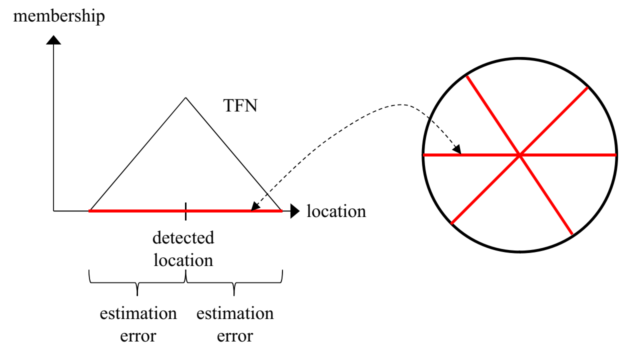

Fig. 1. Modeling the inaccuracy of positioning a user using a triangular fuzzy number.

2. Most LAS applications have not been developed in consideration of a cost-benefit analysis (Cesta, Oddi, & Smith, 2002). One reason for this is that massive government support has obviated a focus on profit; another reason is the difficulty of collecting relevant information on client or users. In addition, relating final user action to a particular LAS is difficult. However, for a LAS to be sustainable, these problems must be overcome to conduct a credible cost-benefit analysis.
3. Although constructing a smoothly operating LAS system is difficult, most LAS applications have not been optimized. One possible reason is that the goal of a LAS is to meet the needs of users that are too diverse to be fully quantified. In addition, certain LAS systems must serve numerous people simultaneously (Espeter & Raubal, 2009). Optimizing performance for numerous users is an extremely complex problem.
4. Most LASs do not operate long term. Thus, ongoing development of new LASs is not necessarily worthwhile.
5. Most LAS applications can be modeled as human-system interaction processes to which human factors or ergonomics are an indispensable aspect, and should be emphasized.

A ubiquitous LAS system was established in this study to recommend suitable and timely services to users. The ubiquitous LAS system achieves the following objectives:

1. It considers the needs of a user, chooses the most suitable service location, and recommends it to the user.
2. When a user arrives at the recommended service location, the service requested by the user is immediately available.
3. The requested service is unavailable before the user arrives in a location because of security and preservation concerns.

This study is based on the following assumptions:

1. Users can communicate with the ubiquitous LAS system through their portable handheld devices.
2. The user's location can be detected.
3. Only service locations located en route from a user's location to the destination are considered.
4. The required service is satisfied by a static location rather than a nomadic provider.
5. A user does not need to accommodate his/her pace to the service preparation process.

To overcome obstacles associated with existing LAS systems, the following treatments were used in establishing the ubiquitous LAS system:

1. A systematic procedure that incorporates a cost-benefit analysis was established for designing the ubiquitous LAS system.
2. A fuzzy mixed-integer programming (FMIP) model was built to solve the problem of recommending the most timely service location to a user. The literature has cited numerous examples of applying fuzzy logic to LASs. For example, fuzzy numbers have been used to approximate user locations and speed (Lin & Chen, 2013). In addition, linguistic variables were used to assist users in expressing needs or evaluating recommendations (Anagnostopoulos & Hadjiefthymiades, 2010; Kotsakis & Ketselidis, 2002). Fuzzy inference rules have also been established to process such linguistic information and to make recommendations (Chen, Xia, & Irawan, 2013; Mateo, Lee, Joo, & Lee, 2006). However, neither linguistic variables nor fuzzy inference rules have been optimized. By contrast, the FMIP model used in this study attempts to minimize user waiting time.
3. To facilitate the problem solving, a fuzzy collaborative problem solving strategy is used to decompose the FMIP problem into several smaller parts that can be handled efficiently. Such a treatment is particularly effective when the LAS receives numerous simultaneous requests, or must select from several service locations.
4. The recommendation result using the proposed methodology is also flexible. More than one service location can be recommended to a user with various levels of relevance.
5. The concept of the most favorable path to a user is defined. The most favorable path leads a user to a region with multiple service locations instead of a single service, to maximize total timeliness.

This paper is organized as follows: Section 2 reviews existing approaches in parallel computing and LAS optimization. Section 3 describes the architecture of the ubiquitous LAS system. Section 4 formulates the problem of finding a timely service location for a user as a FMIP problem, and discusses how to find the most favorable path to a user. To help solve the FMIP problem, the problem is decomposed into several smaller sub-problems that can be handled with a fuzzy collaborative problem solving strategy. An experiment was conducted in downtown Taichung City, Taiwan to evaluate the effectiveness of the proposed methodology, and is described in Section 5. Finally, a conclusion is provided in Section 6.

2. Previous work

Optimizing a LAS is a controversial topic. Numerous LASs involve human decision-making processes, such as the decision-making process involved in whether to follow the results of an online restaurant recommendation system. However, human decision-making is not strictly optimizing in an economical and mathematical sense (Simon, 1995). Rational decision-making differs from unbounded rationality, optimization under constraints, and satisfying constraints, and cannot be resolved simply by applying certain heuristics (Espeter & Raubal, 2009). In addition, representing people's subjective feelings using a simple Likert scale is inappropriate. For example, user perceptions regarding the possibility of an error can be adequately expressed with a lognormal scale instead (Huang et al., 2001).

Optimizing a LAS is a difficult task. First, a bulk of information may require processing, resulting in an optimization model that is extremely large. In addition, such data are dynamic and often incomplete (Kotsakis & Ketselidis, 2002), challenging the adaptability and robustness of the optimization model. Furthermore, user preferences for the recommended LAS are unclear, vague, inconsistent, and even difficult to quantify. Therefore, setting a single objective function that is applicable to everyone is difficult. In this regard, fuzzy logic has been applied to model user preferences using linguistic terms (Kotsakis & Ketselidis, 2002). Cultural