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MOBILE SYSTEMS

Ubiquitous Multicriteria Clinic Recommendation System

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Abstract Advancements in information, communication, and sensor technologies have led to new opportunities in medical care and education. Patients in general prefer visiting the nearest clinic, attempt to avoid waiting for treatment, and have unequal preferences for different clinics and doctors. Therefore, to enable patients to compare multiple clinics, this study proposes a ubiquitous multicriteria clinic recommendation system. In this system, patients can send requests through their cell phones to the system server to obtain a clinic recommendation. Once the patient sends this information to the system, the system server first estimates the patient's speed according to the detection results of a global positioning system. It then applies a fuzzy integer nonlinear programming–ordered weighted average approach to assess four criteria and finally recommends a clinic with maximal utility to the patient. The proposed methodology was tested in a field experiment, and the experimental results showed that it is advantageous over two existing methods in elevating the utilities of recommendations. In addition, such an advantage was shown to be statistically significant.

Keywords Ubiquitous computing · Distant medical care · Recommendation system · Fuzzy integer nonlinear programming (FINLP) · Ordered weighted average (OWA) · Ambient intelligence

Introduction

Taiwan's national health insurance system provides a considerable amount of subsidies to clinics and hospitals. Therefore, private clinics are ubiquitous in Taiwan. Consider, for example, a small region in Nantun district, Taichung City (Fig. 1). More than 150 clinics are available in an area of just 1 km^2. Although these clinics were registered for providing treatments of various departments, many of them provide cross-department treatments. For example, it is common for an ear, nose, and throat clinic to provide general medicine. This phenomenon provides patients numerous choices when they require treatment.

Advancements in information and communication technologies have led to various opportunities to medical care [1] and education [2]. Applications of ubiquitous computing technologies, such as telemedicine or distant medical care, are receiving increasing attention from physicians, information system scientists, and practitioners [3, 4]. Hu et al. [5] examined the factors influencing physicians' acceptance of telemedicine technologies. They analyzed four factors, namely perceived usefulness, perceived ease of use, attitude, and usage intention. Chau and Hu [6] conducted a similar study. Bardram et al. [7] mentioned that a crucial function of ubiquitous computing in medical applications is to move the clinical computer support closer to the clinical work setting. Cho et al. [8] established a web-based system that enables patients to input their glucose levels to achieve ubiquitous monitoring. Vidyarthi and Jayaswal [9] considered the problem of clinic location allocation with stochastic demand and congestion, and proposed an efficient solution to the problem. Simulated data were used to test the effectiveness of the proposed method.

A patient can visit a clinic or make an appointment by telephone. However, a patient may be required to travel a long

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Fig. 1 Distribution of clinics in a small region

distance to arrive at a specific clinic, and then wait for a long period before being treated. Appointments made by telephone are usually assigned low priorities, and patients who make appointments by telephone are treated later compared with other patients. Web-based systems are a potential solution to solve these problems. However, such systems are usually provided by large hospitals only, and such hospitals do not accept an appointment for the same day when a patient calls. Thus, it is still inconvenient for patients to compare multiple clinics and choose the most suitable one. Cultural differences are another problem. In Taiwan, when a foreigner uses Google Maps in English instead of Chinese to search for a nearby clinic, the search results are considerably limited (Fig. 2).

To help patients to compare multiple clinics, even when they are on the move, a ubiquitous multicriteria clinic recommendation system was established in this study. In this system, users can make an appointment to a clinic through their mobile phones and reach the clinic exactly when it is their turn, minimizing the necessity for them to wait in line. Specifically, the waiting time of a patient in a clinic is minimized. The incentive is a patient's willingness to visit a clinic that is a little farther to avoid unnecessary waiting. However, this incentive is limited. Therefore, another concern is that a patient should arrive at a clinic as soon as possible, which is equivalent to finding the shortest path to the clinic, as conducted in most existing mobile guides [10]. Furthermore, a patient usually has unequal preferences to different clinics and doctors, and this should be considered when designing recommendation systems. Therefore, the ubiquitous clinic recommendation system was designed in the current study to achieve four objectives. The novelty of this study lies in the following aspects:

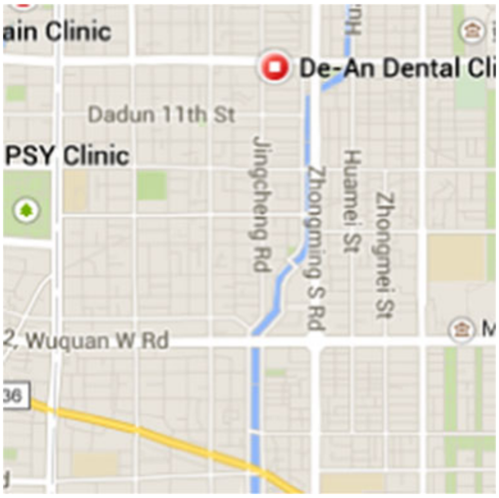


Fig. 2 Searching the same region with Google Maps in English

(1) Similar topics have rarely been investigated in the past.
(2) The applicability of the proposed system is based on a user's willingness to trade travel time for waiting time and the preference for a clinic or doctor, which is also an innovative attempt.
(3) To calculate the travel time, the system estimates the location and speed of a user through the global positioning system (GPS) on the user's cell phone. However, some estimation errors [10] exist. To address this, fuzzy sets [11] are used to model uncertain parameters to generate a robust recommendation.

The rest of this paper is organized as follows. From a systemic perspective, the architecture and operational procedure of the ubiquitous multicriteria clinic recommendation system is introduced in Section 2. Various concerns of a user are also addressed in this section using a hybrid system of fuzzy integer nonlinear programming (FINLP) and ordered weighted average (OWA). In addition to an illustrative example, a field experiment that involves comparing the proposed methodology with two existing methods is presented in Section 3. Finally, Section 4 concludes this study and presents some directions for future research on similar topics.

Ubiquitous multicriteria clinic recommendation system

System architecture

In previous studies, similar ubiquitous service systems have typically been modeled as three-layer client–server systems: the client layer, communication layer, and server layer. However, to ensure the successful operation of the proposed ubiquitous multicriteria clinic recommendation system, the cooperation of clinics is required. A clinic is expected to provide the name of the current doctor, the earliest time a new patient can be treated, and other information. This results in a three-plus-one client–server system (Fig. 3). However, the connection to clinics is not always stable or even available.

The operational procedure of the entire system is described as follows. First, patient sends a request and his/her basic data (including name and birthday) by using his/her cell phone. This information is transmitted to the system server through a communication service provider. After estimating the patient's speed according to the detection results of the GPS system on his/her cell phones, the system server searches the system database and employs the proposed methodology to conduct an analysis and make an optimal recommendation. Finally, the clinic with the maximal utility and the path leading to the clinic are transmitted to the patient.

Determining the "no-wait" clinic and path

In the proposed methodology, the waiting time after a patient arrives at clinic k is minimized:

$$Min\,\tilde{Z}_1=\tilde{s}(-)\left(t_c+\tilde{d}_{(k)}\right) \tag{1}$$

where $\tilde{s}$ is the available time, t_c is the current time, $\tilde{d}_{(k)}$ is the travel time from the start position to the k-th clinic, and $(-)$ denotes fuzzy subtraction. The patient must arrive at the recommended clinic before the scheduled time for beginning the treatment:

$$\tilde{s}\geq t_c+\tilde{d}_{(k)} \tag{2}$$

The travel time can be calculated as follows:

$$\tilde{d}_i=\sum_{j<i,l_{ji}\neq\infty}x_{ji}\left(\tilde{d}_j(+)\tilde{l}_{ji}\right),\ i=1\sim(k) \tag{3}$$

$$\sum_{j<i,l_{ji}\neq\infty}x_{ji}=1,\ i=1\sim(k) \tag{4}$$

$$x_{ji}\in\{0,1\},\ i=1\sim(k);\ j<i;\ l_{ji}\neq\infty \tag{5}$$

where $\tilde{d}_i$ is the travel time from the start position to the ith location, x denotes the connection status between locations ($x_{ji}=1$ if a connection exists between locations i and j, and $x_{ji}=0$ if otherwise), and $\tilde{l}_{ji}$ is the path length between these two locations. This results in an FINLP model that is difficult

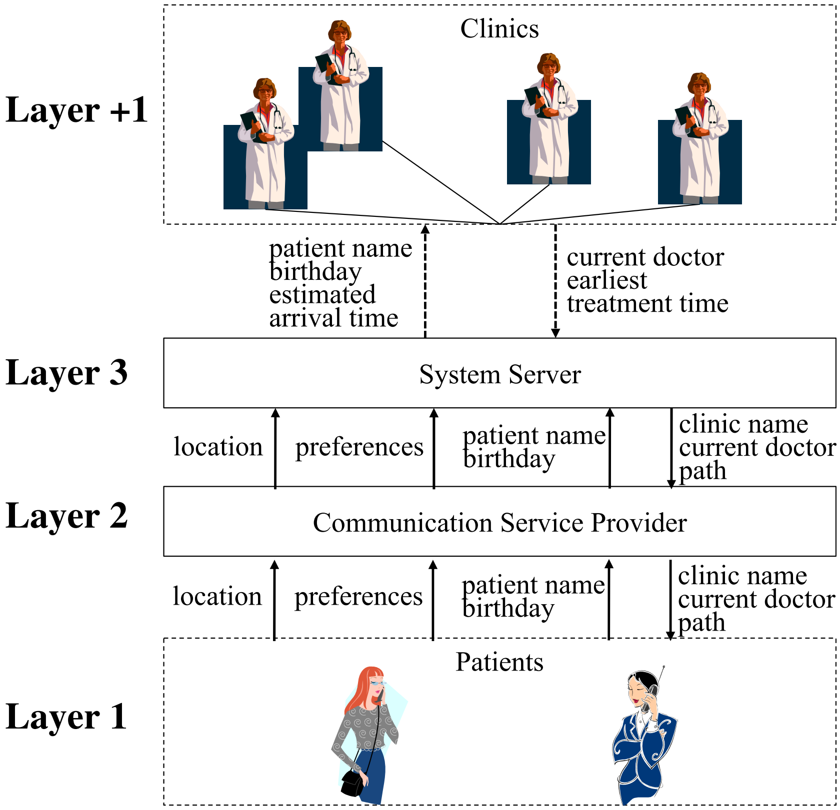


Fig. 3 Architecture of the ubiquitous multicriteria clinic recommendation system

to solve. To convert the FINLP model into an equivalent crisp problem that is easier to solve, the satisfaction level of no-wait is maximized instead as follows:

$$\text{Max}\, Z_2 = \mu_{\tilde{s}(-)\left(t_c+\tilde{d}_{(k)}\right)}(0) \tag{6}$$

$\mu_{\tilde{s}(-)}\left(t_c+\tilde{d}_{(k)}\right)(0)$ can be calculated according to the extension principle [12] as follows:

$$\mu_{\tilde{s}(-)\left(t_c+\tilde{d}_{(k)}\right)}(0) = \sup_{0=s-\left(t_c+d_{(k)}\right)} \min\left(\mu_{\tilde{s}}(s), \mu_{\tilde{d}_{(k)}}\left(d_{(k)}\right)\right) \tag{7}$$

which is equivalent to the following constraints

$$\left(\mu_{\tilde{s}(-)\left(t_c+\tilde{d}_{(k)}\right)}(0)-\mu_{\tilde{s}}(s)\right)\left(\mu_{\tilde{s}(-)\left(t_c+\tilde{d}_{(k)}\right)}(0)-\mu_{\tilde{d}_{(k)}}\left(d_{(k)}\right)\right) = 0 \tag{8}$$

$$\mu_{\tilde{s}(-)\left(t_c+\tilde{d}_{(k)}\right)}(0)\leq\mu_{\tilde{s}}(s) \tag{9}$$

$$\mu_{\tilde{s}(-)\left(t_c+\tilde{d}_{(k)}\right)}(0)\leq\mu_{\tilde{d}_{(k)}}\left(d_{(k)}\right) \tag{10}$$

if $\mu_{\tilde{s}(-)}\left(t_c+\tilde{d}_{(k)}\right)(0)$ must be maximized. Without loss of generality, $\tilde{s}$ and $\tilde{d}_{(k)}$ can be approximated with triangular fuzzy numbers (TFNs),

$$\tilde{s} = (s_1,\ s_2,\ s_3) \tag{11}$$

$$\tilde{d}_{(k)} = \left(d_{(k)1},\ d_{(k)2},\ d_{(k)3}\right) \tag{12}$$

Therefore,

$$\mu_{\tilde{s}}(s) = \min\left(\max\left(\frac{s-s_1}{s_2-s_1},0\right),\max\left(\frac{s-s_3}{s_2-s_3},0\right)\right) \tag{13}$$

$$\mu_{\tilde{d}_{(k)}}\left(d_{(k)}\right) = \min\left(\max\left(\frac{d_{(k)}-d_{(k)1}}{d_{(k)2}-d_{(k)1}},0\right),\max\left(\frac{d_{(k)}-d_{(k)3}}{d_{(k)2}-d_{(k)3}},0\right)\right) \tag{14}$$

Equation (13) can be replaced by the following constraints:

$$\left(\mu_{\tilde{s}}(s)-m_{sL}\right)\left(\mu_{\tilde{s}}(s)-m_{sR}\right) = 0 \tag{15}$$

$$\mu_{\tilde{s}}(s)\leq m_{sL} \tag{16}$$

$$\mu_{\tilde{s}}(s)\leq m_{sR} \tag{17}$$

$$m_{sL}\left(m_{sL}-\frac{s-s_1}{s_2-s_1}\right) = 0 \tag{18}$$

$$m_{sL}\geq\frac{s-s_1}{s_2-s_1} \tag{19}$$

$$m_{sL}\geq 0 \tag{20}$$

$$m_{sR}\left(m_{sR}-\frac{s-s_3}{s_2-s_3}\right) = 0 \tag{21}$$

$$m_{sR}\geq\frac{s-s_3}{s_2-s_3} \tag{22}$$

$$m_{sR}\geq 0 \tag{23}$$

Similarly, Eq. (14) can be replaced by the following constraints:

$$\left(\mu_{\tilde{d}_{(k)}}\left(d_{(k)}\right)-m_{dL}\right)\left(\mu_{\tilde{d}_{(k)}}\left(d_{(k)}\right)-m_{dR}\right) = 0 \tag{24}$$

$$\mu_{\tilde{d}_{(k)}}\left(d_{(k)}\right)\leq m_{dL} \tag{25}$$

$$\mu_{\tilde{d}_{(k)}}\left(d_{(k)}\right)\leq m_{dR} \tag{26}$$

$$m_{dL}\left(m_{dL}-\frac{d_{(k)}-d_{(k)1}}{d_{(k)2}-d_{(k)1}}\right) = 0 \tag{27}$$

$$m_{dL}\geq\frac{d_{(k)}-d_{(k)1}}{d_{(k)2}-d_{(k)1}} \tag{28}$$

$$m_{dL}\geq 0 \tag{29}$$

$$m_{dR}\left(m_{dR}-\frac{d_{(k)}-d_{(k)3}}{d_{(k)2}-d_{(k)3}}\right) = 0 \tag{30}$$

$$m_{dR}\geq\frac{d_{(k)}-d_{(k)3}}{d_{(k)2}-d_{(k)3}} \tag{31}$$

$$m_{dR}\geq 0 \tag{32}$$

Subsequently, according to the arithmetic for TFNs [13], Eq. (3) can be decomposed into

$$d_{i1} = \sum_{j<i,l_{ji}\neq\infty} x_{ji}\left(d_{j1}+l_{ji1}\right) \tag{33}$$

$$d_{i2} = \sum_{j<i,l_{ji}\neq\infty} x_{ji}\left(d_{j2}+l_{ji2}\right) \tag{34}$$

$$d_{i3} = \sum_{j<i,l_{ji}\neq\infty} x_{ji}\left(d_{j3}+l_{ji3}\right) \tag{35}$$

Finally, the following FINLP problem is formed:

$$\begin{aligned}
&\text{Max} \quad Z_2 = \mu_{\tilde{s}(-)\left(t_c+\tilde{d}_{(k)}\right)}(0)\\
&\left(\mu_{\tilde{s}(-)\left(t_c+\tilde{d}_{(k)}\right)}(0)-\mu_{\tilde{s}}(s)\right)\left(\mu_{\tilde{s}(-)\left(t_c+\tilde{d}_{(k)}\right)}(0)-\mu_{\tilde{d}_{(k)}}\left(d_{(k)}\right)\right)=0\\
&\mu_{\tilde{s}(-)\left(t_c+\tilde{d}_{(k)}\right)}(0) \le \mu_{\tilde{s}}(s)\\
&\mu_{\tilde{s}(-)\left(t_c+\tilde{d}_{(k)}\right)}(0) \le \mu_{\tilde{d}_{(k)}}\left(d_{(k)}\right)\\
&\left(\mu_{\tilde{s}}(s)-m_{sL}\right)\left(\mu_{\tilde{s}}(s)-m_{sR}\right) = 0\\
&\mu_{\tilde{s}}(s) \le m_{sL}\\
&\mu_{\tilde{s}}(s) \le m_{sR}\\
&m_{sL}\left(m_{sL}-\frac{s-s_1}{s_2-s_1}\right) = 0\\
&m_{sL} \ge \frac{s-s_1}{s_2-s_1}\\
&m_{sR}\left(m_{sR}-\frac{s-s_3}{s_2-s_3}\right) = 0\\
&m_{sR} \ge \frac{s-s_3}{s_2-s_3}\\
&\left(\mu_{\tilde{d}_{(k)}}\left(d_{(k)}\right)-m_{dL}\right)\left(\mu_{\tilde{d}_{(k)}}\left(d_{(k)}\right)-m_{dR}\right) = 0\\
&\mu_{\tilde{d}_{(k)}}\left(d_{(k)}\right) \le m_{dL}\\
&\mu_{\tilde{d}_{(k)}}\left(d_{(k)}\right) \le m_{dR}\\
&m_{dL}\left(m_{dL}-\frac{d_{(k)}-d_{(k)1}}{d_{(k)2}-d_{(k)1}}\right) = 0\\
&m_{dL} \ge \frac{d_{(k)}-d_{(k)1}}{d_{(k)2}-d_{(k)1}}\\
&m_{dR}\left(m_{dR}-\frac{d_{(k)}-d_{(k)3}}{d_{(k)2}-d_{(k)3}}\right) = 0\\
&m_{dR} \ge \frac{d_{(k)}-d_{(k)3}}{d_{(k)2}-d_{(k)3}}\\
&d_{i1} = \sum_{j<i,l_{ji}\neq\infty} x_{ji}\left(d_{j1}+l_{ji1}\right)\\
&d_{i2} = \sum_{j<i,l_{ji}\neq\infty} x_{ji}\left(d_{j2}+l_{ji2}\right)\\
&d_{i3} = \sum_{j<i,l_{ji}\neq\infty} x_{ji}\left(d_{j3}+l_{ji3}\right)\\
&\sum_{j<i,l_{ji}\neq\infty} x_{ji} = 1,\ i = 1\sim(k)\\
&x_{ji}\in\{0,1\},\ i = 1\sim(k);\ j<i;\ l_{ji}\neq\infty\\
&\mu_{\tilde{s}(-)\left(t_c+\tilde{d}_{(k)}\right)}(0),\ \mu_{\tilde{s}}(s),\ \mu_{\tilde{d}_{(k)}}\left(d_{(k)}\right),\ m_{sL},\ m_{sR},\ s,\ m_{dL},\\
&\quad m_{dR},\ d_{(k)},\ d_{i(1)},\ d_{i(2)},\ d_{i(3)}\ge 0,\ i = 1\sim(k)
\end{aligned}$$

The feasible region of the FINLP problem is usually discrete because the number of clinics that are reachable by a patient is limited. However, a recommended clinic can be obtained using various approaches (e.g., through different routes and at various speeds). These properties render the FINLP problem a special optimization problem. Methods suitable for addressing problems involving discrete feasible regions include the OWA operator [14, 15], decision rules, artificial neural network approximation [16], global random search [17], and simplicial linear interpolation [18].

Considering preferences for a clinic and doctor

A patient usually prefers a particular clinic. To discriminate a user's preference for a specific clinic, OWA concepts are adopted in the proposed methodology.

OWA is particularly suitable for addressing a problem involving a discrete feasible region [14, 19], such as that of the FINLP problem described in the previous section. In addition, OWA is effective for solving multicriteria optimization problems. It is also easy to implement, making it particularly suitable for online applications. However, OWA has some drawbacks. First, a decision strategy must be prespecified, and the decision strategy must be adjusted continuously to optimize performance. Second, after the OWA is applied, some alternatives may exhibit the same weight, forming ties that must be broken somehow. To resolve these drawbacks, several advanced OWA operators have been developed in recent years; such operators include the basic defuzzification distribution (BADD) OWA operator [19], additive neat BADD OWA operator [20], intuitionistic OWA operator [21], and most preferred OWA operator [22].

In the proposed methodology, the following criteria are assessed:

(1) No-wait: The score in this regard is calculated as follows:

$$S_{(k)1} = \left\lceil \frac{Z_2}{0.2} \right\rceil \tag{36}$$

(2) Shortest path: This is based on the assumption that a patient is not always willing to achieve no-wait at the expense of a longer travel time:

$$\min Z_3 = \begin{cases} \dfrac{d_{(k)}-\max\limits_l \delta_{(l)}}{\delta_{(k)}-\max\limits_l \delta_{(l)}} & \mathit{if} \quad \delta_{(k)} < d_{(k)} \le \max\limits_l \delta_{(l)} \\ 0 & \mathit{otherwise} \end{cases}$$

Table 1 Some examples of decision strategies for OWA ($K = 3$)

Decision Strategy	α	$\{w_m\}$
Optimistic	0.001	{0.9989, 0.0007, 0.0004}
Moderately optimistic	0.3	{0.7192, 0.1662, 0.1145}
Neutral	1.0	{0.3333, 0.3333, 0.3333}
Moderately pessimistic	3.0	{0.0370, 0.2593, 0.7037}
Pessimistic	10.0	{0.0000, 0.0173, 0.9827}

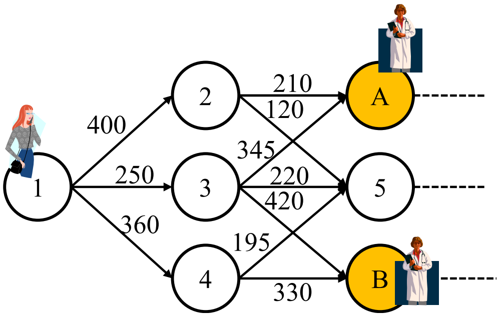


Fig. 4 Illustrative example

where $\delta_{(k)}$ is the shortest path length to clinic k; that is,

$$\delta_{(k)} = \min d_{(k)} \tag{37}$$

The score in this regard is calculated as follows:

$$S_{(k)2} = \left\lceil \frac{Z_3}{0.2} \right\rceil \tag{38}$$

(3) Preference for a clinic: Linguistic terms such as "very low (VL)," "low (L)," "moderate (M)," "high (H)," and "very high (VH)" can be used to naturally represent a patient's preference for a specific clinic. These linguistic terms can be ranked on a crisp or fuzzy scale [23]. The score in this regard is calculated as follows:

$$\mathrm{VL}: S_{(k)3} = 1, \mathrm{L}: S_{(k)3} = 2, \mathrm{M}: S_{(k)3} = 3, \mathrm{H}: S_{(k)3} = 4, \mathrm{VH}: S_{(k)3} = 5$$

without loss of generality.

(4) Preference for the current doctor: A patient usually has unequal preferences for various doctors in a clinic. Such preferences can be expressed using the same linguistic terms as defined in (3). The score in this regard is calculated as follows:

$$\mathrm{VL}: S_{(k)4} = 1, \mathrm{L}: S_{(k)4} = 2, \mathrm{M}: S_{(k)4} = 3, \mathrm{H}: S_{(k)4} = 4, \mathrm{VH}: S_{(k)4} = 5$$

Table 2 Optimization results

Clinic	No-wait path	Z_2
A	1->2->A	0.337
B	1->4->B	0.158

Table 3 The performance of the clinics

Criterion	Clinic A Performance	Clinic B Performance	Clinic A Score	Clinic B Score
Z_2	0.337	0.158	2	1
Z_3	0.200	0.000	2	1
Z_4	"M"	"H"	3	4
Z_5	"L"	"M"	2	3

These scores are aggregated using the following OWA algorithm:

Step 1. Specify a decision strategy. Table 1 shows some examples of decision strategies. The value of α associated with a decision strategy determines the weight assigned to the ordered alternatives:

$$w_m = \left(\frac{m}{K}\right)^{\alpha} - \left(\frac{m-1}{K}\right)^{\alpha}, m \in \{1, \ 2, \ 3, \ 4\} \tag{39}$$

Step 2. Assume that the score of alternative k on criterion m is $S_{(k)m}$; k ranges from 1 to K, m ranges from 1 to 4. Sort $\{S_{(k)m} | k = 1 \sim K\}$ along m to obtain $\{W_{(k)m} | k = 1 \sim K, \ W_{(k)m} \geq W_{(k)m-1}\}$ for each m.

Step 3. Calculate the utility of each alternative as follows:

$$U_{(k)} = \sum_{m=1}^{4} w_m W_{(k)m} \tag{40}$$

Step 4. Choose the alternative k that maximizes $U_{(k)}$.

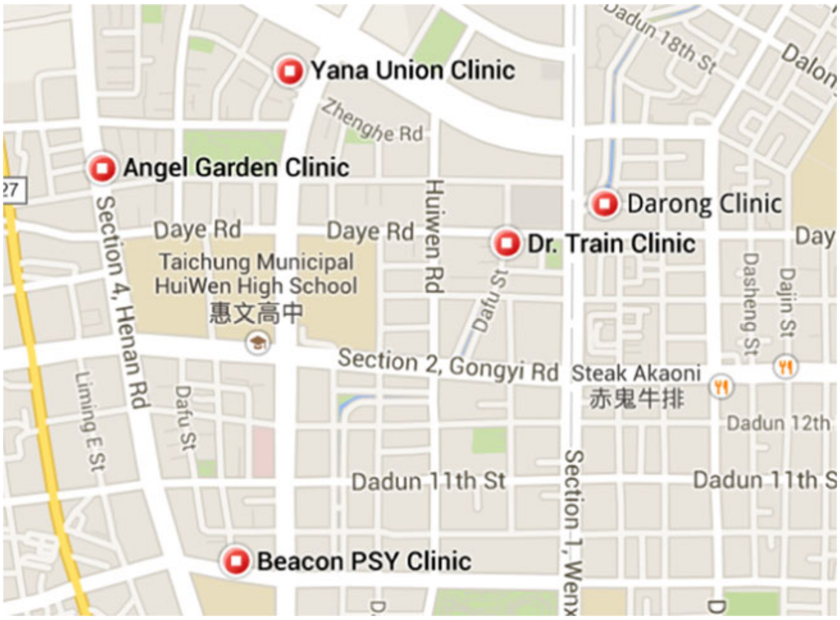
Illustrative example

An example (Fig. 4) is presented to demonstrate the operation of the proposed methodology. Seven nodes are shown in the figure. The distance between any two nodes is shown above (or below) the arc connecting the two nodes. The unit of distance is meter. A patient, starting from Node #1, is visiting a clinic. The patient sends a recommendation request to the system server through his/her cell phone. After receiving the request, the system server estimates the location and speed of the patient according to the detection results obtained by the GPS receiver on the patient's cell phone. The patient is

Table 4 The sorted scores

Clinic	Sorted results
A	{3, 2, 2, 2}
B	{4, 3, 1, 1}

Fig. 5 Experimental region



assumed to walk 16 m in 5 s, and the detection error is 10 m. The patient's speed can be approximated as follows:

$$(16-10,\ 16,\ 16+10)/5*60 = (72,\ 192,\ 312)\ \mathrm{m/min}$$

Two clinics, Clinic A and Clinic B, are available in the nearby region and can be recommended to the patient. The current time t_c is set to zero. The earliest times ($\tilde{s}$) Clinics A and B can treat the patient are estimated to be (5, 10, 15) and (8, 12, 16) min from now, respectively.

First, for both Clinics A and B, an FINLP problem is solved to optimize the no-wait satisfaction level. The results are summarized in Table 2.

Subsequently, the satisfaction level of the shortest path, Z_3, is evaluated for both no-wait paths (Clinics A and B), and the resulting levels are 0.200 and 0.000, respectively. The patient is then requested to express his/her preference for a specific clinic and current doctor. The responses for the clinics are M and H, respectively, and those for the available doctors are L and M, respectively.

Table 3 shows a summary of the performance of the clinics and corresponding scores of the clinics. Table 4 shows the sorted results. The system administrator is assumed to choose the moderately optimistic decision strategy (see Table 1). Thus, the OWAs (or utilities) of the two clinics are derived as 2.66 and 3.28, respectively.

Without other concerns (e.g., planning multiple users simultaneously), Clinic B is the optimal choice.

Experiment

To assess the effectiveness of the proposed methodology, a field experiment was conducted in a small region in Nantun District, Taichung City, Taiwan. The area of the experimental

Fig. 6 Abstract road map

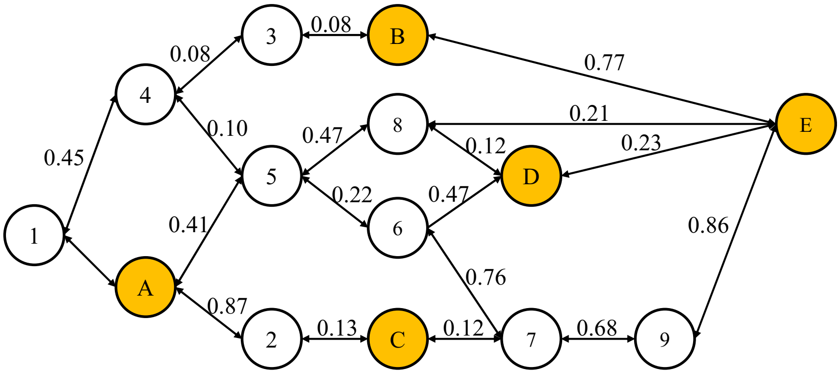


Table 5 Earliest each clinic can treat a new patient

Clinic	$\tilde{s}$
A	(9:45 AM, 10:00 AM, 10:15 AM)
B	(10:30 AM, 10:40 AM, 10:50 AM)
C	(9:30 AM, 9:35 AM, 9:40 AM)
D	(11:00 AM, 11:20 AM, 11:30 AM)
E	(9:45 AM, 10:00 AM, 10:05 AM)

Table 7 Recommendation results obtained using the proposed methodology

Patient #	Recommended Clinic	Path	Utility
1	A	4->5->A	4.564
2	B	1->A->3->B	4.307
3	D	6->D	4.412
4	D	8->A->D	4.564
5	E	9->E	4.307
6	C	5->A->2->C	4.097
7	A	4->5->A	4.154
8	D	8->E->D	4.307
9	E	2->A->5->6->D->E	4.494
10	C	9->E->D->6->5->A->2->C	4.097

region (Fig. 5) is 2.68 km^2. To facilitate a logical interpretation of the problem to be analyzed, an abstract road map of the experimental region was created (Fig. 6). This road map comprised only major roads and their intersections. Five clinics are available in the experimental region, and they are indicated as A–E, respectively. These clinics can also be searched using Google Maps in English. Table 5 shows the earliest times each clinic could treat a new patient in the beginning of the experiment. The name of the doctor serving the current shift is also provided to a patient so that he/she could express his/her preference for the doctor.

Ten patients, starting from different locations, requested recommendations from the system server. The location of each patient was detected using the GPS system on the patient's cell phone. Table 6 shows other contextual information requested by the system server. According to the results of two detections, the speed of a patient was estimated with a fuzzy value (Table 6). This table reflects the real situation that, in Taiwan, patients' preferences are very imbalanced and only a few clinics and doctors can be very popular while others are not.

The recommendation results obtained using the proposed methodology, including the most suitable clinic and path for each patient, are summarized in Table 7. Each patient's utility, considering no waiting, the shortest path, and preferences for clinics and doctors, was optimized.

The proposed methodology was compared with two existing methods, the just-in-time approach [11] and shortest path approach. Because a patient was not actually guided using either of the two methods, the results of the application of these two existing methods were just estimations. The objective of the just-in-time approach is to minimize the waiting time of each user when he/she arrives at the recommended service location. Table 8 shows a summary of the recommendation results obtained using the just-in-time approach. Because the speed of a patient was estimated with a fuzzy value, the estimated waiting time was also a fuzzy value. A membership value of zero (i.e., being just-in-time) in the estimated waiting time was maximized by the recommended clinic. However, just-in-time clinics were not available for Patients #6 and #7. Therefore, such patients must visit the clinic later or wait.

Table 6 Context information of the patients

Patient #	Start Location	Request Time	Estimated Speed (km/h)	Preferences for the Clinics	Preferences for the Current Doctor
1	near node #4	8:30:12 AM	{9.7, 10, 10.3}	{VL, L, M, L, L}	{H, L, H, L, L}
2	near node #1	8:32:23 AM	{14.7, 15, 15.3}	{L, VH, L, H, M}	{L, H, L, M, H}
3	near node #6	8:34:04 AM	{32.7, 33, 33.3}	{M, M, H, H, L}	{M, L, H, H, L}
4	near node #8	8:41:53 AM	{14.7, 15, 15.3}	{L, L, M, VH, H}	{M, L, M, H, H}
5	near node #9	8:43:59 AM	{22.7, 23, 23.3}	{M, L, L, L, H}	{H, L, L, M, M}
6	near node #5	8:44:21 AM	{29.7, 30, 30.3}	{L, L, VH, L, L}	{L, L, H, L, L}
7	near node #4	8:46:58 AM	{22.7, 23, 23.3}	{M, L, H, L, M}	{M, L, H, L, M}
8	near node #8	8:56:52 AM	{25.7, 26, 26.3}	{L, M, M, M, L}	{L, M, H, H, L}
9	near node #2	9:01:55 AM	{19.7, 20, 20.3}	{L, L, L, M, VH}	{L, M, L, M, H}
10	near node #9	9:03:27 AM	{10.7, 11, 11.3}	{H, M, VH, M, M}	{H, L, H, L, L}

Table 8 Recommendation results obtained using the just-in-time approach

Patient #	Recommended Clinic	Estimated Waiting Time (min)
1	C	{0, 0, 1}
2	C	{0, 0, 3.33}
3	C	{0, 0, 2.99}
4	A	{0, 18.57, 38.76}
5	E	{0, 13.78, 18.81}
6	–	–
7	–	–
8	E	{0, 13.71, 21.74}
9	E	{0, 4.47, 12.57}
10	A	{0, 6.58, 28.90}

The shortest path approach is the most prevalent method used in this field. Google Maps also belongs to this type of method in which a user is directed to the closest service location. Table 9 shows the recommendation results obtained using the shortest path approach.

Compared with the two existing methods, the proposed methodology performed more satisfactorily in distributing patients among the clinics (Fig. 7), thus balancing the loads on the clinics. This is crucial in managing a location-based service.

Subsequently, the waiting times of all patients obtained using the three methods were compared, and Fig. 8 depicts the results. The waiting time obtained using the proposed methodology was an actual value, whereas those obtained using the two existing methods were estimated and defuzzified using the center-of-gravity method. The shortest path approach tended to incur more waiting time. Conversely, the proposed methodology reduced the waiting time effectively for most patients.

Finally, the utilities of all patients achieved using the three methods were compared (Fig. 9). For patients guided by the just-in-time approach, ties existed and the utilities were equal to the average of all alternatives. The proposed methodology was advantageous over the two existing methods in simultaneously assessing the needs of a patient in multiple regards.

A paired *t* test was conducted to verify the advantage of the proposed methodology in effectively elevating the utility of a patient.

H_{a0}: When the utility must be elevated, the performance of the proposed methodology is the same as that of the existing methods.

H_{a1}: When the utility must be elevated, the performance of the proposed methodology is more effective than that of the existing methods.

Table 10 shows the results. The null hypothesis H_a was rejected at $\alpha = 0.01$, indicating that the proposed methodology was superior to the existing methods when the utility was to be elevated.

Conclusions

Advancements in information, communication, and sensor technologies have led to numerous opportunities in medical care and education. This study investigates an innovative application of ubiquitous computing to distant medical care and proposes a ubiquitous multicriteria clinic recommendation system. This system is particularly useful for patients seeking a clinic in a region containing numerous clinics. In the proposed methodology, a patient sends a request and other related information to the system server through his/her cell phone. When this information and request are received, the system server estimates the patient's speed according to the detection results of the GPS in the patient's phone. To recommend a clinic that maximizes the utility to a patient, the system server applies the FINLP–OWA method to optimize and compare the utilities of clinics. In this manner, four concerns of a patient, namely no-wait, the shortest path, preference for a clinic, and preference for a doctor, can be assessed simultaneously.

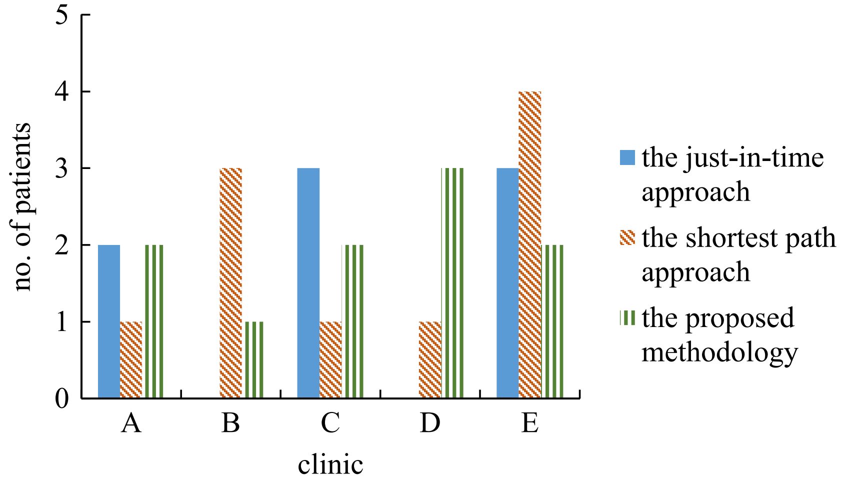
In addition to an illustrative example, the system was also tested in a field experiment conducted in a small region in Nantun District, Taichung City, Taiwan. Two existing methods, the just-in-time approach and shortest path approach, were used in this experiment for comparison. The results are outlined as follows:

(1) Using the proposed FINLP–OWA method for the assessment effectively distributes patients among clinics, thus balancing the loads on the clinics.
(2) The just-in-time approach fails to return no-wait clinics for some patients. After considering multiple criteria, the

Table 9 Recommendation results obtained using the shortest path approach

Patient #	Recommended Clinic	Shortest Path	Path Duration (km)
1	B	4->3->B	1.000
2	A	1->A	0.092
3	D	6->D	0.469
4	E	8->E	1.050
5	E	9->E	0.857
6	B	5->4->3->B	0.265
7	B	4->3->B	0.163
8	E	8->E	1.050
9	C	2->C	0.133
10	E	9->E	0.857

Fig. 7 Performance of the three methods in distributing patients



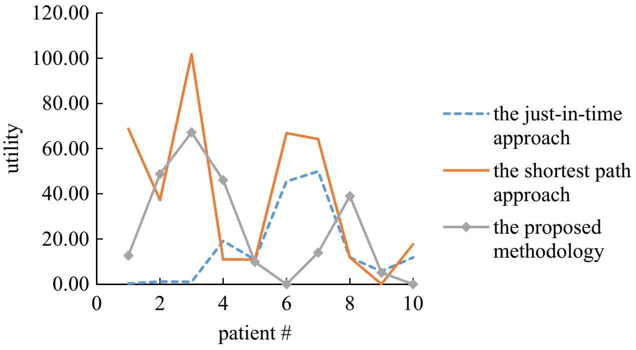


Fig. 8 Waiting times of all patients obtained using the three methods

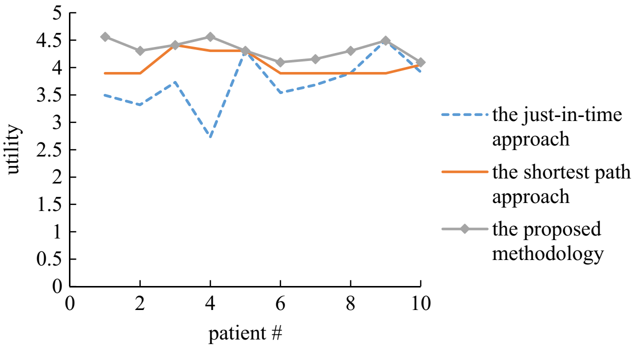


Fig. 9 Utilities of patients achieved using the three methods

proposed system reduces the waiting time effectively for most patients.

(3) The advantage of the proposed methodology in elevating utilities over the two existing methods is statistically significant.

(4) The simultaneous consideration of multiple objectives was shown to be an effective way to improve the utilities of clinic recommendation for patients on the move.

(5) The effectiveness of clinic recommendation can be further enhanced by the cooperation among different clinics. However, this is based on the premise that these clinics are willing to cooperate and provide more operating information, such as availability and the average waiting time, to the ubiquitous multicriteria clinic recommendation system.

In practice, a patient may not be willing to answer all questions asked by the client–server app. This means that the system server has to justify when the received information is incomplete. This constitutes a direction for future research.

Table 10 Results of the paired *t* test

	the proposed methodology vs. the just-in-time approach	the proposed methodology vs. the shortest path approach
Number of observations	10	10
Pearson's Correlation Coefficient	−0.205	0.274
Degree of freedom	9	9
t statistic	3.478	3.811
$P(T <= t)$ one-sided	0.0035	0.0021
$P(T <= t)$ two-sided	0.0070	0.0041

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