A Heuristic Algorithm and a System for Vehicle Routing with Multiple Destinations in Embedded Equipment*

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Abstract

A heuristic algorithm appropriate for vehicle routing problem with multiple destinations in embedded equipment is presented. The algorithm is applied to the local routing and global routing respectively. Based on the consideration of road conditions and special direction roads (one-way street, banning of turn in crossing, etc.), a routing system adopting the algorithm is developed in embedded equipment ARM9. Experimental results from the routing system prove the efficiency of the presented heuristic algorithm in embedded equipment.

***Keywords**: Vehicle routing problem, Heuristic algorithm, Embedded, GIS*

1. Introduction

With the fast development of traffic program and Intelligent Traffic Systems, onboard vehicle routing systems developed in embedded equipment have a great potential market and application prospect. These systems can help drivers find a reasonable traveling path, and provide them with optimal routing information according to their destinations. As a result, it will save drivers' time, reduce their costs, decrease traffic jams and environment pollution, and bring about enormous social and economical benefits.

In existing embedded vehicle routing systems, classical shortest path algorithms have been adopted, such as Dijkstra algorithm, Bellman-Ford-Moore algorithm, Floyd algorithm, A* algorithm etc.. However, these algorithms can only present the shortest path between two nodes, but not produce solutions to the problem with several different destinations in real time according to the change of road condition. Since in most of time a driver will sequentially visit several destinations once, an algorithm developed in embedded equipment that can combines the local optimization between two destinations with the global optimization of the whole path is desired. In addition, more and more new-building roads and other means of transportation emerge recently, which provide more choice for travelers and ensure unblocked routes, and some traffic rules such as one-way street and the banning of turn in crossing are widely adopted, which increase the complexity of traveling and the hardness of the routing system development.

Considering the two requirements, we investigate a heuristic algorithm that can be applied to the local optimization and global optimization at a time and can run soundly in embedded equipment. Based on the consideration of road conditions and special direction roads (one-way street, banning of turn in crossing, etc.), we develop the routing system in embedded equipment ARM9 to achieve the following goals:

- Find out an optimal or satisfactory path starting from the origination and passing through the destinations appointed by the driver in sequence.
- Provide the driver with the shortest travel distance path, least cost path, or least travel time path according to the driver's preference.
- Take the road condition and the special traffic rules into consideration to figure out the applicable optimal path in real time.
- Display the final result to the driver in the onboard terminal.

2. Literature review

Vehicle Routing Problem (abbr. VRP) in a routing system is a NP-hard problem. There are several

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researches in areas of algorithm for VRP and onboard vehicle routing systems. Many algorithms have been proposed to find out shortest paths with multiple destinations, including Willard's tabu search(TS) algorithm [1], Osman's simulated annealing algorithm [2], Holland's genetic Algorithms [3], and Ombuk's hybrid algorithm which divided routes into groups by genetic algorithm and then optimized these routes by Tabu search [4].Bent and Van Hentenryck [5] minimized the number of routes and then minimized transportation cost by large neighborhood search. William Ho et al. [6] focused on VRP with multiple depots and developed a genetic algorithm (GA) hybridized with several heuristics. LIU Ai Long et al. [7] presented an automatic vehicle navigation system based on GPS、GIS and embedded system. Pei Z. Z. et al. [8] discussed the optimal routing algorithm incorporating some typical characters of city road networks, such as restrictions of one-way and turning. Heung-Suk Hwang [9] developed an integrated model using heuristic and genetic algorithms, and developed a graphical user interface, GUI-type program, Dongeui GA-VRP Solver. Though the existing algorithms can find out optimal or satisfactory solutions in static road environment, they cannot produce solutions to the multi-destination problems in real time according to the change of road condition nor deal with some special instances, for example, one-way street and the banning of turn in crossing [10]. Furthermore, because embedded equipments with little EMS memory run slowly, traditional optimization routing algorithms are complex and very difficult to find out optimal routes in onboard terminals with limited memory. The mainly objective of existing shortest path algorithm is to obtain the shortest travel distance between two points, which cannot meet the various demands of drivers, like obtaining the path with shortest travel time, the path with least operation cost, and etc.. Therefore, a new algorithm is desired, which can run efficiently in embedded equipment, obtain different routing objectives according to the preferences of drivers, and solve the vehicle routing problem with multiple destinations according to the road conditions.

Numerous researches have been done on location technology, route finding, wireless communication, and all kinds of assist drive systems [11]–[17], which help drivers to arrive at destinations along optimal paths. All these studies had improved assist drive systems' intelligence level. However, lacking of associate information like jammed sections, weather state and special direction roads (one-way street, banning of turn in crossing, etc.), most of these systems only guide drivers to drive along some pre-determined paths; they cannot generate optimal paths in real time. A more effective system which can consider all special road conditions and generate optimal paths according to drivers' preferences in real time should be developed.

The remainder of the paper is organized as follows. In section 3, we describe the vehicle routing problem with multiple destinations in detail and divide the problem into two parts: local routing and global routing. In section 4, the proposed heuristic search algorithm for routing problems onboard is described, evaluation functions for local routing and global routing are defined respectively and road characteristics are considered, such as one-way street, jam and road mending. In section 5, the embedded vehicle routing system with multiple different destinations is designed and realized, which utilizes eSuperMap components and runs on GIS platform and windows CE, and the application of the new system in Dalian City is discussed. In section 6, we conduct an experiment to compare the proposed algorithm with the traditional Dijkstra algorithm. Finally, we draw our concluding remarks and summarize future research directions in section 7.

3. Problem description

Vehicle routing problems with multiple destinations arise when a driver wants to visit several destinations in sequence at one time. An example with 3 destinations is shown in figure 1.

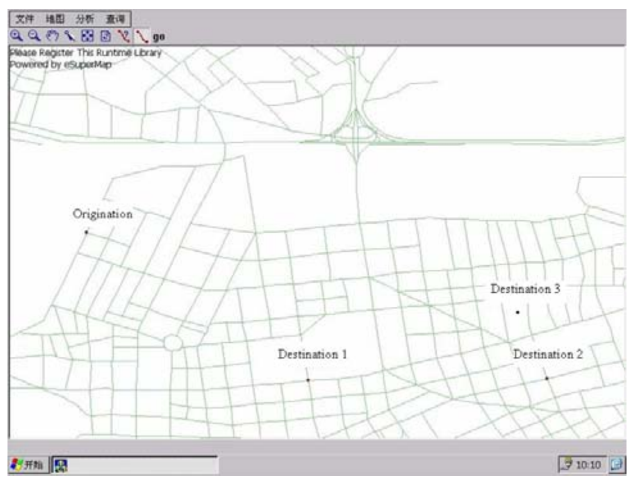

Figure 1. Vehicle routing with 3 destinations

The goal of the routing system is:

1) Find out an optimal or satisfactory path starting from the origination and passing through the destinations appointed by the driver in sequence;

2) Provide the driver with the shortest travel distance path, least cost path, or least travel time path according to the driver's preference;

3) Take the road condition and the special traffic

rules into consideration to figure out the applicable optimal path in real time;

4) Display the final result to the driver in the onboard terminal.

In order to realize the above goal, we divide the routing problem into two parts, local routing and global routing. Global routing is to find out an optimal path that passes through every destination for the driver. Local routing is to find out an optimal path between two nodes involved.

The global routing problem can be described as follows:

A series of nodes are represented by the set of $\{p_1, p_2, \ldots, p_n\}$. The origination is p_0, the distance (time or cost) of the optimal route between p_i and p_j (where, $i, j=0,1,\ldots, n, i\neq j$) is $d(p_i, p_j)$, which is the result of the local routing. The problem is to find a set $X=\{1, 2, \ldots, n\}$ (elements in set X are the number of the destination nodes) and an array $N(X)=\{v_1, v_2, \ldots, v_n\}$, where $v_i \in X$, which will minimize the global path length (total time or total cost).

$$MinD\left(N\right) = d\left(p_0, p_{v_1}\right) + \sum_{i=1}^{n} d\left(p_{v_i}, p_{v_{i+1}}\right) \tag{1}$$

Equation (1) indicates that global routing depends on the results of computation of $d(p_i, p_j)$ in local routing. The algorithm for local routing should be simplified and emphasis should be placed on local routing and the treatment of traffic rules.

The local routing is the basis of the global routing. The important step in local routing is the represent of the road network.

The features of road network are:

- Node: the crossing of road or the end-point of dead ends.
- Arc: the directed link between two nodes.
- Weight of arc: the quantitative expression of a road or some attributes. Different road attributes can be chosen according to different optimization objectives, for example, road length, average travel time and average travel cost can be treated as the weight of arc corresponding with the road.

When nodes, arcs and weights of arcs are defined, road network is translated into directed graph. Thus the problem of finding the optimal route between two nodes in road networks is converted into the shortest path problem in graph theory. Though the storage amount will increase when the road network is represented by directed graph, it is still necessary to express the road network by directed graph when the road-impedance function related to traffic flow is adopted, since the traffic flows in two directions of road are different in general. Furthermore, directed graph can treat some unusual conditions, such as one-way street and banning of turn in crossing, etc.

The solution of the shortest path is determined by the road weight. The corresponding road weight can be defined by difference optimization objectives, which is the weight of each arc if it is represented by graph. There are three kinds of optimization objectives in the routing system: the shortest travel distance, the least travel time and the least operational cost. The methods of defining the road weight are as follows:

- $w_r=l_r$, if the optimization objective is the shortest travel distance;
- $w_r=t_a$, if the optimization objective is the least travel time;
- $w_r=c_a$, if the optimization objective is the least operational cost.

Where

w_r is the road weight;

l_r is the road length;

t_a is the average travel time spent in the road;

c_a is the average operational cost of trucks spent in the road;

t_a and c_a are decided by several factors such as the road level, road number, road gradient and traffic condition etc.

4. Heuristic algorithm for the vehicle routing problem with multiple destinations

Since the onboard vehicle routing runs in the embedded equipment that has limited EMS memory, it is necessary to find an optimal algorithm with little EMS memory when an enormous road network is treated. On the other hand, it is very important for dynamic routing system to be efficient, which requires the running of an algorithm to finish in a short time. Therefore, it is necessary to reduce an algorithm's running time. To achieve the above mentioned goals, the precision of the algorithm may be ignored. An algorithm, which uses little EMS memory and little time and produces an ideal solution that has small difference with the optimal solution, is suitable to the routing system. It should find a good tradeoff among the precision of the algorithm, the storage amount and the computing time.

A* algorithm, the most popular heuristic search technique, introduces known global information when selecting the next node. It estimates the distance between present node and the terminal to measure the probability of the node's position belonging to the optimal route, so that the node with bigger probabilities will be selected and the efficiency of search will be improved.

If the heuristic evaluation function h(v) does not compute highly the costs from current node to destination, h(v) is called to be possibility. And then A* algorithm must discover the optimal route if it exists.

The search space is smaller than that of Dijkstra algorithm. The search space of the A* algorithm and the improved Dijkstra algorithm is shown in figure 2.

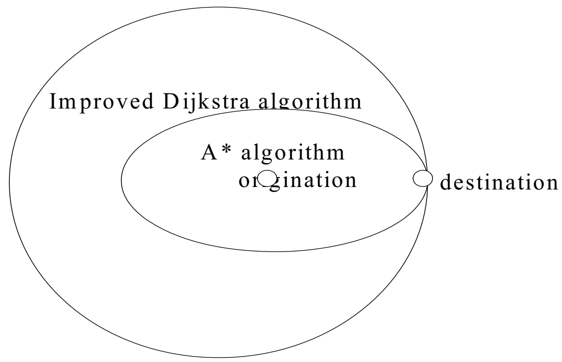

Figure 2. Search Space of the two algorithms

Evaluation function h(v) used to estimate the possibility of a node belonging to the optimal route is the most important parameter. Whether it is defined reasonably will directly affect the search efficiency. In this system, according to the practical requirement, the evaluation functions of the global and local routing should be defined differently.

Owing to the limitation of the total number of destinations, the solution to the local routing problem should be precise so that results for the entire system will be more precise. The evaluation function in local path searching is defined as equation (2) according to the system's practical requirement.

$$h^*(j) = \begin{cases} 0, j = t \\ \min\{c(j,k) + e(k,t) : \forall (j,k) \in A\}, j \neq t \end{cases} \tag{2}$$

where,

k: all nodes adjacent to node j;

t: the destination node;

c(j,k): the distance from j to k;

e(k,t): the estimation of the distance from k to the destination node;

A: the arc set of the road network.

For global routing, the evaluation function should be redefined. Since there is no fixed destination in global path searching, $h^*(j)$ should be replaced by h′(j) in equation (2):

$$h'(j) = \min\{c(j,k) \quad \forall (j,k) \in A\} \tag{3}$$

where,

k: all nodes adjacent to node j;

c(j,k): the distance from j to k;

A: the arc set of the road network.

Table OPEN and CLOSED are used when A* algorithm is used to find the optimal path, where table OPEN preserves nodes already been created and not been checked, and table CLOSED records nodes already been visited. Both tables are realized by arrays for saving EMS memory. Node fingers are reserved in the tables. The searching algorithm for optimal path is as follows:

Step 1: establish empty tables OPEN and CLOSED, and then add original node to table OPEN.

Step 2: the first node among the last batch of nodes in OPEN is dequeued and saved in CLOSED.

Step 3: if the number of nodes in CLOSED equals to that of total nodes, then the optimal route is found, go to step5.

Step 4: expand node n to create all following nodes which are not ancestors. Calculate values of h(i) for each following node, and methods for treating i are as follows: a) if i is not in OPEN or CLOSED, then insert i to OPEN, and array all nodes in OPEN by sort ascending, go to step 2; b) otherwise, compare d(i) and dTotalLength(i), if d(i)<dTotalLength(i) then replace dTotalLength(i) with d(i), and if i is in CLOSED, go to step 2.

Step 5: trace the route from destination node back to original node, and then the optimal route will be found.

The flow chart of the algorithm is shown in Figure 3.

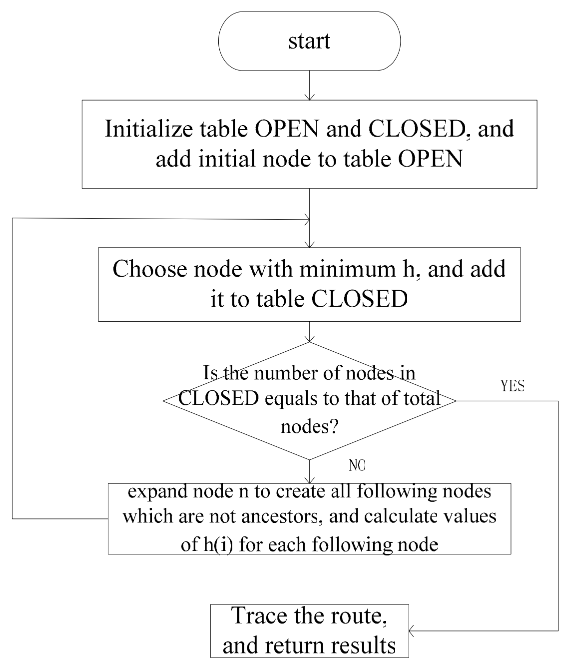

Figure 3. The flow chart of A* algorithm

5. The vehicle routing system with multiple destinations in embedded equipment

To satisfy the requirement of user's working environment, the GIS-based and onboard vehicle routing system is required to have the features such as human-computer interaction, expandability and alterability in zone etc.. The system is designed to satisfy the requirements of consuming little information storage space, real time and universality, and developed in PC by using Component GIS and ODBC. After realizing system functions, the system is repotted to Personal Digital Assistant (abbr. PDA) in order to extend its application fields.

5.1. The architecture of the vehicle routing system

Developed in Windows CE, eVC++ platforms, vehicle routing system integrates the embedded-GIS and DB, uses the digital map as the basic database, and provides an ideal route according to users' requirements. The system consists of three parts: 1) Man-machine Interface: obtain users' requirements and display results; 2) Digital Map Database: obtain road data in the digital map; 3) Road condition database: obtain traffic information. The architecture of the vehicle routing system is shown in figure 4.

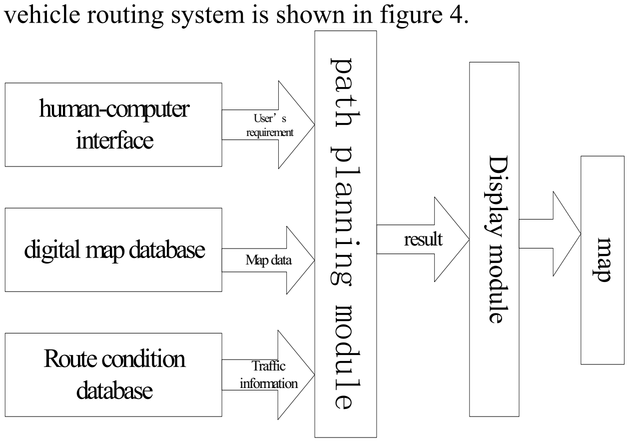

Figure 4. The architecture of the vehicle routing system based on embedded-GIS

5.2. The entire model of the system

The system uses the digital map of Dalian City as the basal database. The data of GIS which the system uses is divided into spatial data and attribute data. The spatial data mainly contains geographic position, shape and the links of the objects related to spatial geometric objects. The data of attributes describes geometric objects' attributes, such as their names, perimeters and codes etc.. They are linked to the functional module of the embedded map—eSuperMap according to the way of interlinkage of objects. The road condition database mainly contains the data related to the road conditions, including unconventional conditions, one-way street, and traffic jam, gradients and etc.. Supported by control widgets of eSuperMap, the functions of drawing, browsing and displaying can be realized by embedding control widgets of eSuperMap into eVC. The entire model of routing system is shown in figure 5.

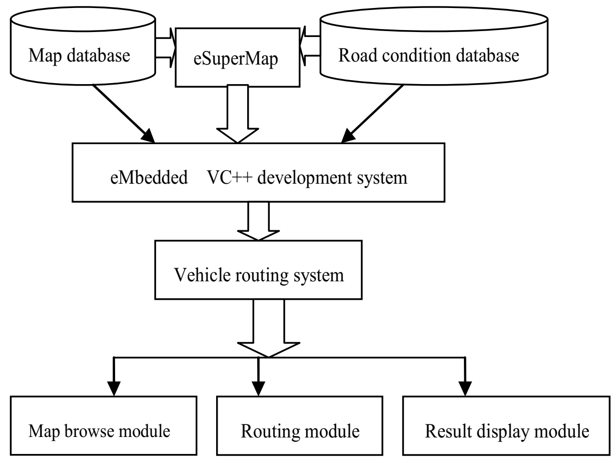

Figure 5. The entire model of the routing system

5.3. System components

- Map Browsing Module

Map browsing module realizes these functions like zooming in, zooming out and move of the map by calling functions in eSuperMap.

Zoom-in(CSeDrawParameters::uaZoomIn): users can control the zoom in amount and select scales.

Zoom-out(CSeDrawParameters::uaZoomOut): users can control the zoom out amount and select scales.

Move(CSeDrawParameters::uaPan): when users move the map, it will move according to the direction and shift quantity.

- Vehicle Routing Module

The vehicle routing module is the core of this system. There are three basic functions in this module. Firstly, users choose the objective of the routing, such as the shortest path or the least travel time etc.. Then the original node and several destination nodes should be chosen in map. Lastly, the optimal path should be found out by the above mentioned heuristic algorithm in shorter time by real-time calculation and displayed in map.

- Human-computer Interface Module

Through the human-computer interface module, users input the origination and destinations. After the vehicle routing is finished, the pathway is displayed in the interface. Human-computer interface includes display interface and input interface in this system. The display interface is the equipment that can translate electric signal into visible images in real time. Now the color LCD is widely used as a display screen. Considering the practical situation of the routing system, the design of input interface aims at security and operational simplification. Now the touch screen is widely used, which is a control facility and can be connected with any displays, such as CRT, LCD or ELD. Users can directly choose their destinations in the digital map shown in a display with a touch screen. The system will solve the vehicle routing problem according to their destinations and show the results in the digital map. In this way it is very easy for users to manipulate the system.

5.4. Disposals of the one-way street and other unconventional conditions

Some unconventional conditions such as one-way street and traffic jam etc. are incorporated in the system design. The system treats roads as directed graphs. The traffic rules are recorded in the road condition database, 0 represents impassability, 1 represents two-way streets, 2 is up-street and 3 is down-street. Traffic rules are defined as variables (nRuleCode) and the data is read from database when routes are searched.

When the routing system is used to figure out the path with shortest travel time, the flux of a road should be considered in order to avoid links with traffic jams. Therefore, a road flux level table stored in the road condition database records the traffic condition of links for 24 hours of a day. The data in the table are from the historical statistic, which doesn't include the abnormal conditions. In the table, the 24 hours are divided into 48 time periods, in which every link has a flux level (see table 1). When the routing module calculates the path with shortest travel time, the travel time will be multiplied by the value of the flux level corresponding with the time period pointed by the driver.

Table 1. Road Flux Level Table

Time periods / Arc ID	i	ii	iii	iv	v	vi	vii	viii	…
a	4	3	1	3	3	2	5	2	…
b	1	3	5	2	2	2	6	3	…
c	4	4	4	2	1	3	2	1	…
d	3	4	1	2	4	1	1	2	…
…	…	…	…	…	…	…	…	…	…

In addition, since there are many gradient roads in Dalian City, gradients of roads are added to the system when solving the least-cost-path problem. The table structure for road conditions in road condition database is shown in Table 2.

Table 2. Table Structure for Roads in Road Condition Database

FIELD	FIELD NAME	FIELD TYPE	FIELD LENGTH	OTHERS
ArcID	arc ID	Int	4	Key
BelongRoadName	belong road name	String	10	
RoadDirection	road direction	Int	2	
GradientLevel	Gradient level	Int	2	

Data in the above two tables can fully describe the three kinds of unconventional conditions of roads: traffic rules, traffic jam and gradients.

5.5. Application of the onboard routing system with embedded GIS

When the nodes selected by users cannot be found in the digital map, the most adjacent nodes will be selected in the map database according to the longitude-latitude of the designated nodes. The process will be realized by the method "FindNearsestNode".

The result of the routing is finally displayed in human-computer interface. An example with 3 destinations realized in Dalian City's digital map is shown in figure 6.

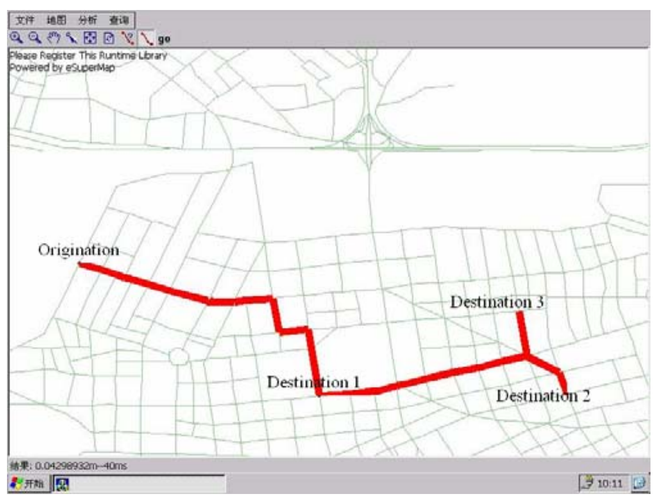

Figure 6. The display of the final result of the routing

6. Experimental results

The most popularly used algorithm in GIS to generate the shortest path between an origin-destination pair is the Dijkstra algorithm. Thus, in order to prove the advantages of the proposed algorithm, we test the proposed algorithm and the typical Dijkstra algorithm on a Yuan Feng YFDVK-2410-I embedded developing board, which has 64M RAM, 32M Flash ROM, and a Samsung

S3C2410 CPU core. Algorithms are coded in Microsoft embedded visual C++4.0, run in the Windows CE.Net operation system.

Origin-destination pairs used in the experiment were chosen randomly within the map of Dalian City road network. Because there are 103 one-way streets out of the 444 main streets in downtown, which accounts for a large portion of the total roads, the disposal of the one-way street is very important, which is one of the advantages of the proposed algorithm and the system.

The evaluation of outcome is judged by the number of total searched nodes between the chosen origin-destination pair, and the total time used by the search process.

We choose ten origin-destination pairs with long distance in Dalian City's digital map. The test results produced by the proposed algorithm and the typical Dijkstra algorithm are shown in Table 3. It can be concluded from table 3 that the proposed algorithm is more effective, which decreases the number of total searched nodes by 24.58% and reduces search time by 41.6%.

Table 3. Comparison between Dijkstra Algorithm and Proposed Heuristic Algorithm

Test number	Typical Dijkstras algorithm		Algorithm in this paper	
	Total searched nodes	Search time (seconds)	Total searched nodes	Search time (seconds)
1	4733	17	3637	9
2	4429	16	3379	10
3	4594	17	3497	9
4	4117	14	3015	8
5	3742	12	2847	7
6	4326	15	3374	8
7	4218	15	3139	9
8	3993	14	3016	8
9	4374	15	3319	10
10	4183	14	2978	9

7. Conclusions

In this paper, an improved heuristic algorithm combining local search with the global search is developed to get the solution to the vehicle routing problem with multiple destinations. The algorithm can achieve three kinds of optimization objectives in the embedded routing system: the shortest travel distance, the least travel time and the least operational cost. The experimental results show that it is more efficient and effective than Dijkstras algorithm. Based on the algorithm, a vehicle routing system developed in an embedded platform is realized, which considers three kinds of unconventional road conditions, one-way streets, traffic jams and gradients of roads. The embedded-GIS platform is applied to the system design and development. The vehicle routing with multiple destinations is realized in the embedded equipment ARM9, which can provide users with ideal routes according to their optimization objectives established by their preference. Though problems occurring in real world are more complicated than those solved in the designed system, the system has strong expansibility because it is developed by Object Oriented technique and convenient to be changed.

The research has the following limitation. The flux of a road is dynamic along with the time of a day. However, limited by the dynamic techniques of detection and analysis of traffic data, the dynamic flux function is hardly obtained. Thus, we use the data of road flux levels obtained from historical statistic, which regards the flux as a static number within a time period. But if the divided time period is too long, a vehicle may finish its travel within one period, which in fact ignores the dynamic traffic condition. If the divided time period is too short, a vehicle may finish its travel through several periods. In this case, we should have considered the different fluxes of a road. In brief, how to record or consider the dynamic flux of a road when planning the shortest time path needs further study.

8. References

[1] Willard, J. A. G.. *Vehicle routing using r-optimal tabu search*[D]. M.Sc. Dissertation. The Management School, Imperial College, London, 1989.

[2] Osman I H. Meta-strategy simulated annealing and Tabu search algorithms for the vehicle routing problem. *Annual of Operational Research*, 1993, 41, pp.77-86.

[3] Holland J. *Adaptation in Natural and Artificial Systems*[M]. University of Michigan Press, 1975.

[4] Ombuki B M, Nakamura M, Osamu M.A hybrid search based on genetic algorithms and tabu search for vehicle routing. *Brock University Technical Report:#CS-02-07*, 2002, 5, pp.1-7.

[5] Bent R. and Van Hentenryck P. A two-stage hybrid local search for the vehicle routing problem with time windows. *Technical Report, CS-01-06, Brown University,* 2001, 9, pp.1-30.

[6] William Ho , Prasanta K. Dey. A Hybrid Genetic Algorithm Approach for the Multi-Depot Vehicle Routing Problem. *Proceedings of International Conference on Logistics and Supply Chain Management*. Hong Kong SAR, China, 5-7, Jan. 2006, pp.2.

[7] LIU Ai long, TIAN Yan, CHEN Tao, YANG Chun-lei. Research and Implementation of Sound Vehicle Navigation System Based on Real time Traffic Restriction and Embedded System. *Journal of Information Engineering University*, 2005, 6(4): pp.99-102.

[8] Pei Zhongzhe, Liu Xiaoming, Ding Jian. The optimal route algorithm in the vehicle Navigation system

incorporating the limits of one-way street and banning in crossing. *Road traffic and security*, 2003(4), pp.26-28.
[9] Heung-Suk Hwang**.** GIS-Based VRP Solver for Supply Chain Network 2-D and 3-D GIS Vehicle Routing Model. *Proceedings of International Conference on Logistics and Supply Chain Management*. Hong Kong SAR, China, 5-7, Jan. 2006.
[10] Zhang Ke, Liu Xiaoming, Wang Xiaojing. Research on route planning system for vehicle automatic navigation. *System engineering*, 2001, 19(2), pp. 48.
[11] S. Q. GUAN, J. LIU, and Q. LENG, "Design of embedded vehicle navigation system," *Computer Engineering and Design*, May 2005, vol. 26, pp.1320-1322.
[12] Y. Furukawa, "Status and future direction of intelligent drive assist technology," in *Proceedings of Intelligent Transportation Systems*, Dearborn, MI USA, 2000, pp. 113-118.
[13] S. H. WANG, and D. H. LI, "Design of mobile terminal of vehicle for monitoring system based on GPRS," *Application Research of Computers*, June, 2005, vol. 22, pp.184-186.
[14] B. CHEN, D. H. LI, and X. YAO, "Design and implementation of an extensible vehicle monitor and control system based on GPRS," *Application Research of Computers*, June, 2005, vol. 22, pp. 175-178.
[15] M. YANG, "Application design and implementation of GPS- GPRS location system vehicle terminals," *Telecommunication Engineering*, March, 2004, pp. 103-106.
[16] D. G. YANG, K. Q. LI, S. F. ZHENG, D. Z. HOU, and X. M. LIAN, "Vehicle technologies in intelligent transport systems," *Automotive Engineering*, Mar. 2003, vol. 25, pp. 223-226.
[17] H. B. YU, and H. L. YU, "Status and prospect of high precision vehicle dynamic navigation technology," *Automobile Technology*, Nov. 2003, pp. 1-4.