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The Fuzzy-AHP Evaluation Method for Unmanned Ground Vehicles

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Abstract: Task driven approach is widely used as an evaluation method for unmanned ground vehicles, however this approach may lead to many teams using the conservative approach to complete the task. Although the competition task can be completed, it has deviated from the goal of technological development. The proposed fuzzy comprehensive evaluation method combined with AHP(fuzzy-AHP) was validated in comprehensive evaluation of unmanned ground vehicles. The fuzzy-AHP evaluation method was successfully applied to evaluate the unmanned ground vehicle in "Future Challenge 2011"(FC'2011). To evaluate unmanned ground vehicles is a problem of multilevel comprehensive evaluation. It should be divided into different levels of evaluation based on the complexity of unmanned ground vehicles environment perception and intelligent behavioral decision-making. The index evaluation system of unmanned ground vehicles is established. Each factor matches with different weight coefficient to highlight the important one. The index weight is determined by AHP, then the fuzzy comprehensive evaluation method is applied to evaluate unmanned ground vehicles. Using fuzzy-AHP evaluation method not only takes into account all factors, but also considers all the information of all levels evaluation. Each factor matches with different weight coefficient to highlight the important evaluation factor. The quantitative results can reflect the actual situation , and facilitate the comparison or order of the result directly.

Keywords: Fuzzy-AHP, unmanned ground vehicle, evaluation, FC'2011

1. Introduction

In the first competition of the DARPA Grand Challenge none of the unmanned ground vehicle finished the route. But in the second competition, five vehicles successfully completed the race. The Third DARPA Grand Challenge was called DARPA Urban Challenge. The competition was composed of 96km urban road environment and the traffic rules must be obeyed by vehicles. Six vehicles successfully completed the race [1]. Australia held Smart Demo event in the field of ITS in September 2005[2]. Europe also ran European Land-Robot Trial(ELROB) similar to the DARPA Grand Challenge in May 2006 to study the perception, navigation and control capabilities of the unmanned ground vehicles in an unknown urban environment in 2007. Since then, ELROB organized four competitions in June 2008, August 2009, May 2010 and June 2011. The competition environment is divided into civil and military parts and alternating each year[3]. The Italian Parma University began Intercontinental Autonomous Challenge departing from Parma in July 20, 2010 which lasted three months and traveled thirteen thousand kilometers[4]. The Google company announced on its official blog the company tested unmanned ground vehicle in October 9, 2010. It has been traveling 140,000 miles[5]. The first Chinese unmanned ground vehicles competition-The 2009 Future Challenge: Intelligent Vehicles and Beyond(FC'09) was the first third-party test and evaluation for unmanned ground vehicles to go out from laboratories into application environments. FC'09 further promoted the development of the test platform and evaluation system[6].

In a sense, the rapid development of unmanned ground vehicles benefits from the preestablished test and evaluation system. None of the unmanned ground vehicles finished the route in the first competition of the DARPA Grand Challenge. However five vehicles successfully completed

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the race in the second competition. The evaluation system has played an important role and formulated the related technical indicators to guide the development of unmanned ground vehicles.

The competition usually cared about whether a vehicle completed the task and the time of completing the task. As a result, many teams used the conservative approach to complete the task, not to complete the task with high quality. For example, in high-density traffic most vehicles preferred to stopping and waiting for a clear opening instead of merging into the traffic as a human driver did[7].

The unmanned ground vehicles should have the natural environment perception and decision-making capacity of intelligent behavior, and ultimately meet or exceed the manual driving. The ”technology-oriented” evaluation is proposed in this study to guide the development of unmanned ground vehicles in the ”natural environment perception and intelligent behavior decision-making” technology direction. The task-driven way of evaluation usually care about if the task can be finished by a vehicle, while, the technology-oriented way of evaluation focus on how unmanned ground vehicles how to complete the task. Therefore, the fuzzy-AHP evaluation method[8] is proposed in this study which guides the unmanned ground vehicle not only to complete the task, but also to complete the task with high standard and high quality.

2. Establishing the Index Evaluation System

To evaluate unmanned ground vehicles is a problem of multilevel comprehensive evaluation. It should be divided into different levels of evaluation based on the complexity of unmanned ground vehicles environment perception and intelligent behavioral decision-making. The characteristics of target object can be reflected by the determined evaluation levels scientifically, objectively and comprehensively. The evaluation levels include evaluation aspects, evaluation elements and evaluation factors. The index evaluation system of unmanned ground vehicles is established by five indexes and eighteen subprime indexes. The five indexes include vehicle control behavior, basic driving behavior, basic traffic behavior, advanced driving behavior and high traffic behavior. Fig.1 shows the index evaluation system of unmanned ground vehicles (VCB denotes vehicle control behavior; BDB denotes basic driving behavior; BTB denotes basic traffic behavior; ADB denotes advanced driving behavior; HTB denotes high traffic behavior).

3. Fuzzy-AHP Method

The fuzzy comprehensive evaluation method combined with AHP (fuzzy-AHP) is proposed in this study. The fuzzy comprehensive evaluation method was applied because of the evaluation of unmanned ground vehicles is a multilevel

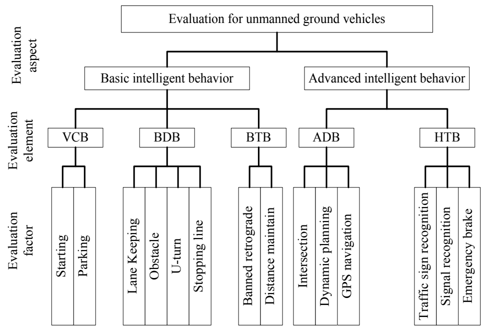

Figure 1 Static obstacle avoidance

comprehensive evaluation pro-blem. The evaluation system should be divided into different levels, and the factor of each level has different importance in the index evaluation system. So the analytic hierarchy process (AHP) is adopted to get the reasonable weight distribution of the evaluation system.

A. The fuzzy-AHP evaluation for single factor

(1) Establishing the evaluation factor set U

$$U = \{u_1, u_2, \cdots, u_i, u_m\} \quad (1)$$

Where, m is the number of the evaluation aspect.

The i-th aspect $u_i (i = 1, 2, \cdots, m)$ can be further divided into

$$u_i = \{u_1, u_2, \cdots, u_j, u_n\}_i \quad (2)$$

Where, n is the number evaluation elements of the i-th evaluation aspect.

The j factor $u_{ij} (j = 1, 2, \cdots, n)$ can be further divided into

$$u_{ij} = \{u_1, u_2, \cdots, u_k, u_p\}_{ij} \quad (3)$$

Where, p is the number evaluation factors of the evaluation element j-th in the evaluation aspect i-th.

(2) Establishing the evaluation grade set V

$$V = \{v_1, v_2, \cdots, v_n\} \quad (4)$$

The same number of the evaluation grade set can be taken by various factors, where n is the number of the evaluation grade set.

(3) Establishing the fuzzy matrix R_{IJ}

The fuzzy matrix of the evaluation element j-th in the evaluation aspect i-th is expressed by R_{IJ}.

$$R_{IJ} = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & & \vdots \\ r_{p1} & r_{p2} & \cdots & r_{pm} \end{bmatrix}_{IJ} \quad (5)$$

Where, each row $(R_i)_{IJ} = (r_{i1}, r_{i2} \cdots r_{ij} \cdots r_{in})_{IJ}$ of R_{IJ} is the evaluation result for the i-th factor r_{ij} is the membership grade of the i-th evaluation factor for the j-th evaluation grade, which reflects the fuzzy relation between each evaluation factors and each evaluation grade.

(4) Establishing the weight coefficient matrix

Each factor has different importance in the evaluation factor system. The analytic hierarchy process (AHP) is adopted to get the reasonable weight distribution of the evaluation system. The judgment matrix of the upper factor for the lower relevant factor can be given through the relative importance comparison of evaluation factors in accordance with definition table of importance [9,10,**?**,11]. Decision-makers compare the degree of importance between the two factors shown in Table.1. The comparison matrix A is got according to the comparison results.

Table 1 Comparison between Factors

	A_1	A_2	$\cdots$	A_n
A_1	a_{11}	a_{12}	$\cdots$	a_{1n}
A_2	a_{21}	a_{22}	$\cdots$	a_{2n}
$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$
A_n	a_{n1}	a_{n2}	$\cdots$	a_{nn}

$$A = [a_{ij}]_{n\times m} \tag{6}$$

The consistency check must be carried on after obtaining the biggest characteristic root λ_{max} of the matrix to ensure the consistency of different factors.

Consistency index $C.I.$ is expressed as

$$C.I. = \frac{\lambda_{max} - n}{n-1} \tag{7}$$

If it meets the following condition, the results of the comparison matrix can be accepted.

$$\frac{C.I.}{C.R.} < 0.1 \tag{8}$$

Where $C.R.$ is the average random consistency index.

The weight coefficient matrix of the evaluation aspect is:

$$A = (a_1 \quad a_2 \quad \cdots \quad a_i \quad \cdots \quad a_m) \tag{9}$$

Where, a_i is the weight value of the i-th evaluation aspect, and meets $0 < a_i \le 1$,

$$\sum_{i=1}^{m} a_i = 1 \tag{10}$$

The weight coefficient matrix of the evaluation element is:

$$A_I = (a_1 \quad a_2 \quad \cdots \quad a_j \quad \cdots \quad a_n)_I \tag{11}$$

Where, a_{jI} is the weight value of the j-th evaluation element in the I-th evaluation aspect, and meets $0 < a \le 1$,

$$\sum_{i=1}^{n} a_{jI} = 1 \tag{12}$$

The weight coefficient matrix of the evaluation factor is:

$$A_{IJ} = (a_1 \quad a_2 \quad \cdots \quad a_k \quad \cdots a_p)_{IJ} \tag{13}$$

Where, a_{kIJ} is the weight value of the k-th evaluation factor in the J-th evaluation element which belongs to the I-th evaluation aspect, and meets $0 < a \le 1$,

$$\sum_{i=1}^{p} a_{kIJ} = 1 \tag{14}$$

(5) Single elements comprehensive evaluation matrix

The comprehensive evaluation of the J-th element in the I-th aspect can be expressed as:

$$B_{IJ} = A_{IJ}R_{IJ} = (a_1 \quad a_2 \quad \cdots \quad a_p)_{IJ} \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & & \vdots \\ r_{p1} & r_{p2} & \cdots & r_{pn} \end{bmatrix} = (b_1 \quad b_2 \quad \cdots \quad b_J \quad \cdots \quad b_n)_{IJ} \tag{15}$$

Where, $j = 1,2,\cdots,n, b_{iIJ} = \sum_{i=1}^{p} a_{iIJ}\cdot r_{ijIJ} = 1$.

The quantitative results can be used to better reflect the real situation because of the impact assessment in computing the results of the various elements and their importance in the evaluation are considered[12].

B. The fuzzy-AHP evaluation of all aspects

The fuzzy evaluation result $B_{IJ}(J = 1,2,\cdots,n)$ of each single element is taken together to form a higher level evaluation matrix R_I. Using the same method get the comprehensive evaluation result $B_i(I = 1,2,\cdots,m)$ of the I-th element combined with R_I and the weight coefficient matrix A_I, form a higher level of matrix R, finally get the comprehensive evaluation matrix B, this matrix is a comprehensive evaluation result:

$$B = A\cdot R = (b_1 \quad b_2 \quad \cdots \quad b_k \quad \cdots \quad b_n) \tag{16}$$

Evaluation of the results of B is not only taking into account all factors, but also considers all the information at all levels of evaluation.

The comprehensive evaluation result can be expressed with a total score. The evaluation criteria membership grade set is $\mu = \{\mu_1 \quad \mu_2 \quad \cdots \quad \mu_k \quad \cdots \quad \mu_n\}$, then the specific score of the comprehensive evaluation result can be calculated. Finally the object can be evaluated according to the score.

$$The\ score = 100B\mu = (b_1\ b_2\ \cdots b_k\ \cdots\ b_n)$$

$$[\mu_1\ \mu_2\ \cdots\ \mu_k\ \cdots\ \mu_n]_T \times 100 = (\sum_{k=1}^{n} b_k\mu_k)\times 100 \tag{17}$$

4. FC'2011

The third Chinese unmanned ground vehicles competition-the 2011 Future Challenge: Intelligent Vehicles and Beyond(FC'2011) sponsored by the National Natural Science

Foundation of China(NSFC) was held on October.20-21, 2011 in Ordos China[13]. The competition environment was changed from a closed road environment to the real road environment compared with the last two competitions. The test environment is complex and unknown for unmanned ground vehicles on 10km real urban road. The competition contents include traffic signs recognition, obstacle avoidance, import, U-turn, intersection, lane changing and so on(See Fig.2-Fig.4). The environment perception and intelligent decision-making of unmanned ground vehicles are comprehensively tested.

With a team statistic data(see Table 2), for example, the concrete fuzzy-AHP evaluation process is introduced.

The comprehensive evaluation form is divided into two evaluation aspects. Each evaluation aspect is divided into different evaluation elements and each element is divided into different evaluation factors. The evaluation aspects, elements and factors are assigned to different weight coefficients. The evaluation grade set can be set to the same number levels:

$V = \{v_1\ v_2\ v_3\ v_4\ v_5\}$

The evaluation process of unmanned ground vehicles is evaluated from the last stage to the higher level. In this study the evaluation stated from the ”vehicle control behavior” element of the ”basic intelligent behavior” evaluation aspect.

(1) Establishing the ”vehicle control behavior” evaluation factor set U_{11}.

$U_{11} = \{starting(u_1)\ parking\ (u_2)\}_{11}$

(2) Establishing the fuzzy evaluation matrix R_{11} of the ”vehicle control behavior” evaluation element.

The fuzzy matrix(see Table.4.1) is expressed by the membership grade using the specialized test method combined with the expert investigation.

$$R_{11} = \begin{bmatrix} 0.2 & 0.7 & 0.1 & 0 & 0 \\ 0.1 & 0.4 & 0.3 & 0.2 & 0 \end{bmatrix}_{11}$$

(3) Establishing the weight coefficient matrix A_{11} of the ”vehicle control behavior” evaluation element.

$$A_{11} = (0.33 \quad 0.67)_{11}$$

(4) Calculating the comprehensive evaluation matrix B_{11} of the ”vehicle control behavior” evaluation factor.

$$B_{11} = A_{11} \cdot R_{11} = (0.133 \quad 0.499 \quad 0.234 \quad 0.134 \quad 0)_{11}$$

This result is the comprehensive evaluation result of the ”vehicle control behavior” evaluation factor. The comprehensive evaluation results of the ”basic driving behavior” and the ”basic traffic behavior” evaluation factor can be got using the same method.

$$B_{12} = (0.11 \quad 0.33 \quad 0.405 \quad 0.064 \quad 0.088)_{12}$$

$$B_{13} = (0.075 \quad 0.175 \quad 0.14 \quad 0.21 \quad 0.35)_{13}$$

(5) Synthesizing the fuzzy evaluation of each evaluation aspects.

Figure 2 Static obstacle avoidance

Figure 3 Dynamic obstacle avoidance

Figure 4 Through the intersection

Figure 5 U-turn

Table 2 Performance of Team A in FC'2011

Evaluation aspect			Evaluation element			Evaluation factor			Evaluation grade V				
No i	u_i	a_i	No j	u_{ji}	a_{ji}	No k	u_{kij}	a_{kij}	v_1	v_2	v_3	v_4	v_5
									Fuzzy matrix				
									Very good	Good	So-so	Bad	Very bad
1	BIB	0.33	1	VCB	0.13	1	Starting	0.33	0.2	0.7	0.1	0	0
						2	Parking	0.67	0.1	0.4	0.3	0.2	0
			2	BDB	0.59	1	Lane Keeping	0.21	0	0.5	0.3	0.2	0
						2	Obstacle	0.11	1	0	0	0	0
						3	U-turn	0.57	0	0.4	0.6	0	0
						4	Stopping line	0.11	0	0	0	0.2	0.8
			3	BTB	0.28	1	Banned retrograde	0.7	0	0	0.2	0.3	0.5
						2	Distance maintain	0.25	0.3	0.7	0	0	0
2	AIB	0.67	1	ADB	0.67	1	Intersection	0.31	0.2	0.6	0.2	0	0
						2	Dynamic planning	0.58	0.4	0.6	0	0	0
						3	GPS navigation	0.11	0.3	0.7	0	0	0
			2	HTB	0.33	1	Traffic sign recognition	0.25	0	0	0	0	1
						2	Signal recognition	0.5	0	0	0	0	1
						3	Emergency brake	0.25	0.2	0.8	0	0	0

The evaluation results B_{11}, B_{12}, B_{13} of each factor form the fuzzy matrix R_1 of "basic intelligent behavior" the higher level aspect:

$$R_1 = \begin{bmatrix} 0.133 & 0.499 & 0.234 & 0.134 & 0 \\ 0.11 & 0.33 & 0.405 & 0.064 & 0.088 \\ 0.075 & 0.175 & 0.14 & 0.21 & 0.35 \end{bmatrix}_1$$

The weight coefficient matrix of the three evaluation elements in the "Basic intelligent behavior" aspect is:

$$A_1 = (0.13 \quad 0.59 \quad 0.28)_1$$

So the comprehensive evaluation result of the "basic intelligent behavior" aspect can be got:

$$B_1 = A_1 \cdot R_1 = (0.1032 \quad 0.3086 \quad 0.3086 \quad 0.114 \quad 0.15)_1$$

Similarly, the comprehensive evaluation result B_2 of the "high-level intelligent behavior" aspect was got, and a high-level fuzzy matrix R was formed. The final evaluation result can be got combined with the weight coefficient matrix A.

$$B = A \cdot R = (0.1936 \quad 0.4204 \quad 0.1296 \quad 0.0376 \quad 0.2153)$$

If the comprehensive evaluation result is expressed by total score, the membership grade set of the evaluation criterion is:

$$\mu = \{1 \quad 0.8 \quad 0.6 \quad 0.4 \quad 0.2\}^T$$

The score of five indexes vehicle control behavior, basic driving behavior, basic traffic behavior, advanced driving behavior and high traffic behavior are:

$$G_{11} = 72.62; G_{12} = 66.02; G_{13} = 45.3;$$

$$G_{21} = 85.3; G_{22} = 36$$

From the result of the evaluation elements we can see the intelligence level of vehicle control behavior, basic driving behavior and advanced driving behavior is high enough to meet the requirement, but the intelligence level of basic traffice behavior and high traffic behavior is low.

The team's comprehensive evaluation score is:

The score=100 Bμ=66.578

5. Conclusion

In this paper we study the evaluation of unmanned ground vehicles. Because the evaluation of unmanned ground vehicles is a multilevel comprehensive evaluation problem, the multilevel indexes evaluation system of unmanned ground vehicles is established based on the complexity of unmanned ground vehicles environment perception and intelligent behavioral decision-making. The fuzzy-AHP evaluation method was successfully applied to evaluate the unmanned ground vehicle in FC'2011. From the quantitative result we can see not only the intelligence level of each evaluation aspect and each evaluation element, but also the intelligence level of unmanned ground vehicles directly. Using fuzzy-AHP evaluation method not only takes into account all factors, but also considers all the information of all levels evaluation. Each factor matches with different weight coefficients to highlight the importance of the evaluation factor. The quantitative results can reflect the actual situation, and facilitate the comparison or the order of the result directly.

The first issue to be developed is the comparison of the delayed model introduced in the present paper with the experimentally measurable quantities. Indeed the mathematical models should reproduce both qualitatively and quantitatively empirical data. The economic growth is a complex phenomenon from which emerges a collective behaviour that cannot be explained by the analysis of the single elements. Therefore the model should reproduce, at least at a qualitative level, the relative emerging collective behaviours. Accordingly our model should be able to match the data on electricity consumption per capita, which is an observable variable.

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