DECISION TABLE SYNTHESIS IN FUZZY ENVIRONMENT FOR INDUSTRIAL ROBOT – TELPHER

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Abstract. To ensure intellectual operation of the robot in decision-making tasks, its control system must have a knowledge base that encompasses a full set of results in the corresponding field. The knowledge base can be based upon several types of decision-making rules, including sets of production rules, which are best presented in the form of decision tables. The present paper investigates the versions of synthesis of decision tables in the fuzzy environment depending on the mutual relationships between criteria. The authors compare three examples that are important for decision table synthesis.

Keywords: artificial intelligence, decision rules, decision tables, decision trees, decision-making criteria, fuzzy sets, linguistic variables, robot.

Introduction

Robot technique has been part of our lives for a while now, and sometimes it can have some intellectual traits. Besides, some systems allow solving managerial and decision-making tasks in the fuzzy environment, where fuzzy sets and linguistic variables dominate, such as positive-small, negative-large, far, near, quite far etc.

Before the *Theory of Fuzzy Sets* by L. A. Zadeh, only the human could work in such an environment. Nowadays, computer systems and robots can operate there with the help of artificial intelligence. One of the basic features of artificial intelligence is the existence of a knowledge base that contains the knowledge in a certain field discovered and gained by humans. One of the essential requirements for the quality of the knowledge base is the coherent structuration and correct formalisation of knowledge so that the computer can readily process the information. Foundation of a knowledge base to solve some problems in decision-making tasks in the fuzzy environment is the main goal of the present research, especially emphasising the performance of the robot technique.

Defining the Problem in Fuzzy Decision-Making

In literature, solutions can be found to decision-making in the fuzzy environment, e.g., the popular Fuzzy TECH 5.55 used to control the telpher [1], inverted pendulum [1], or road traffic control systems [2-4]. Despite the lack of numerical information, decision-making in the control of the telpher, inverted pendulum and road traffic control systems is entrusted to computers and robot techniques. All the mentioned examples have a similar structure and type of solution.

Decision-making takes place in a polycriterial environment (2 or 3 criteria). Input information is presented in the form of linguistic variables [5; 6], e.g., gradations of distance: *far, medium, close* and *right next to (zero).*

Output value – fuzzy values also have a linguistic gradation, e.g., the gradation of an engine power: *positive big (PB), positive medium (PM), zero (Z), negative medium (NM), negative big (NH).* The compliance of the linguistic variables with the real environment is ensured by the relational functions [7; 8]. In all examples, knowledge bases are formed from the production rules “IF...THEN”, which must also be predefined [9; 10]. They ensure the compliance of the fuzzy decisions (THEN) with the input situations represented by the condition part (IF). It presents the largest difficulty in these kinds of tasks – how to formulate a set of production rules and determine a full set. Another important goal of the present research is to find out how much the content of the production rules depends on both the specificity of the task, and the type and formal criteria, and what decision-making rules are to be taken into account and used in real solutions.

Types of Knowledge Bases Used in Practical Tasks

Decision rules (their essence, form, order) can be set in many ways:

- decision trees;
- sets of production rules;

- frame structures;
- decision tables etc.

The distinctive features of these forms determine their usability in solving practical tasks. The decision trees due to their transparency and simplicity are preferred in manual processing, while sets of production rules and frame structures are used in computer processing. However, all of these methods have one downside – they all work best with predefined rules, but are not so well suited for the synthesis of these rules. If the task is to create a decision rule, the most suitable is the table form, which allows seeing and using different regularities to easily make adjustments and also ensures a foundation of a full set of rules. A combination of decision rules in a table form that makes up a knowledge base is used in all the aforementioned examples. It is only natural, because the filling of the knowledge base is one of the main objectives of these tasks.

Without the above-mentioned examples we can still imagine such a task. Let us imagine the following task. Cargo is being transported from the barge to the coast ramp over a field, Fig. 1. The field could be either empty or partly filled with people. In each situation, a safe route must be chosen which would not endanger people. The input information could consist of:

- border of a field with humans;
- wind speed;
- risk level of the cargo.

What is meant by the risk level is the type of cargo – whether it is piece goods, bulk freight, or high-risk cargo (sharp metals, gas cylinders etc.) In this example, criteria are coordinated, because an increase of any of the criteria just moves the route away from the people, only question is – how far.

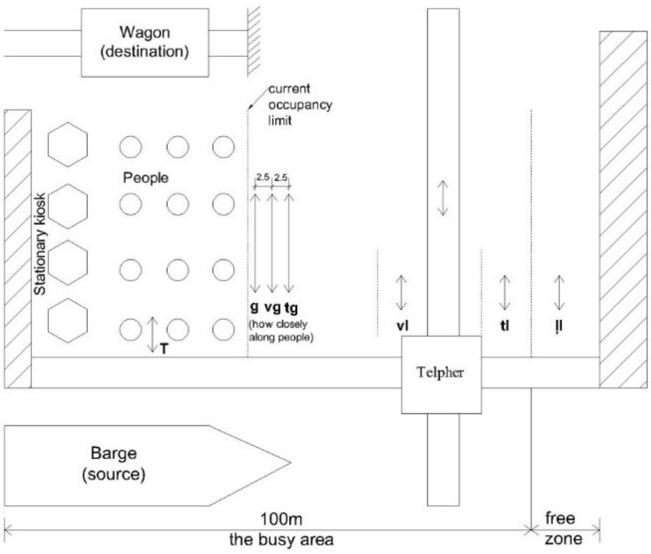

Fig. 1. **Example with cargo movement across the square**

From the analysis of these examples, it is possible to conclude that:

1. Different methods have to be used to fill the decision tables in different tasks;
2. Each type of the task requires its own methodology of filling the table;
3. To be more objective, it is beneficial to take into account different regularities when creating the methodology for solving the tables for each type of the tasks;
4. Rules should be clearly formulated so that all the experts involved in the solving process would interpret them similarly (if the tables are filled by a team of experts according to all the rules of the experiment);
5. There can be situations, when it is necessary and possible to take into account the priority of the criteria, but it can also be unnecessary and can reduce the level of objectivity.

Methods of Filling the Table

Let us continue with development of practical methods for some types of tasks. A typical decision table in the fuzzy environment with linguist variables is presented in Fig. 2. Vertically and horizontally in the table the linguistic gradations of the first criterion and the second criterion can be found. Cells of the table are meant for writing down the fuzzy decisions. A case is examined where one expert creates the fuzzy decisions. The actions of the expert group are not discussed. Let us list the main requirements for filling the table:

1. The entries have to be as close to the objective reality as possible;
2. The methodology of filling the table has to be clear;
3. If the task requires to take into account the priorities of the criteria, there has to be a way how to implement it in the table.

		Second criterion			
		small	average	large	very large
First criterion	small	1.diag			2.diag
	average				
	large				
	very large				

Fig. 2. **Decision-making table stencil**

A Case with Contradictory Criteria

A typical example of the situation is from the field of road traffic control (the third example with a highway and pedestrian crossing). There are two criteria:

1. Number of vehicles on the highway;
2. Waiting time of the pedestrians.

The criteria are mutually exclusive – green light either for vehicles or for pedestrians. Both criteria in the top left corner of the table are low, while the ones in the bottom right corner are high. It means that the strongest rivalry is in the area around the first diagonal and filling of it is most ambiguous. An opposite situation is in the area around the second diagonal, where a value of one criterion "small" meets a value of the second criterion "very large", thus determining the decision.

Thus, in the top right corner of the table around the second diagonal or on top of the first diagonal the fuzzy decisions will be in favour of the second (horizontal) criterion – continue the green light for the vehicles (T). In the bottom left corner of the table or under the first diagonal the decision will be in favour of the first (vertical) criterion – switch the green light for the pedestrians (P).

It is possible to modify the elements of the first diagonal:

a) if pedestrians are to be given priority (schools, kindergartens, old people's homes, hospitals, residential areas with visually impaired people), then entries of the diagonal (??) are replaced with P;
b) if priority is to be given to vehicles, then entries of the diagonal are replaced with T.

In some cases, priority can be given to the elements which in Fig. 3 are labelled as P? and T?. These are places where experts can express their different opinions, and these places can be solved with the formal methods of the expert evaluations. It should be noted that in the filling of the elements P?, T?, ?? a side criterion can be used – the distance between the vehicles driving in a single lane. If this distance is short, there is some risk of crashes, which is why the mentioned elements can be replaced with T. If the distance is long, the elements can be replaced with P.

		Number of vehicles			
		small	average	large	very large
Waiting time of the pedestrians	small	??	T?	T	T
	average	P?	??	T	T
	large	P	P	??	T?
	very large	P	P	P?	??

Fig. 3. **Decision-making table**

A Case with Matching Criteria

A typical example of the situation is the transportation of cargo over a field that is partly filled with people, (the fourth example, Fig. 1). There are three criteria:

1. Distribution of the people in the field (border);
2. Risk level of the cargo;
3. Wind speed.

The criteria are well-matched because the higher value, the further away the crane route is moved away from the people. The criteria do not compete with each other even if their values do not match. If one criterion allows a shorter distance from the people, then the decision is made according to the second criterion, which does not allow it. The situation is made more difficult by the fact that the fuzzy decisions are complex. The first criterion determines the serial number of the virtual corridor of the possible route, which, in turn, determines (approximately) the distance by which the crane will have to be moved right so that it operates behind the border of the field of humans.

Linguistic gradations of the variable are:

- S – straight over the field;
- vlr – very little to the right;
- lr – little to the right;
- qfr – quite far to the right;
- fr – far to the right;
- vfr– very far to the right.

The second part of the fuzzy decision is made of the inner distance in the corridor, which determines just how close to the humans the cargo can be transported taking into account its risk level and the wind speed.

Linguistic gradations of the variable are:

- r – right along the border;
- qf – quite far away, (up to 2.5 m);
- f – far away from the border. (2.5-5 m).

These are the fuzzy decisions:

- qfr/r – quite far to the right, right along the border;
- fr/qf – far to the right, quite far away;
- vfr/f – very far to the right, far away from the border.

As the environment consists of three criteria, there will be many decision tables according to the number of gradations of the first criterion. Let us look at one of the possible decision tables consisting of the wind speed and the risk level of the cargo. The table corresponds with the corridor on the first criterion with the value – far to the right, Fig. 4.

First two conditions of the methodology for filling the table are obvious:

1. if there is no cargo (idling), there is no risk and the first row of the column is filled with *S* – straight over the people;
2. if this table is made for the situation fr – far to the right, then fuzzy decisions in all other cells will have the first part as fr. If the table were meant for the situation lr – little to the right, then the first part of the decisions in the cells would be lr.

   Further analysis refers to the second part of the fuzzy decisions.

3. The wind speed and the risk level of the cargo do not compete with each other. The bottom right corner of the table features the maximum values of both criteria. That is why the decisions are in favour of a long distance from the border of the field of people – far away from the border (f);
4. The top left corner of the table features minimums of both criteria. That is why the decisions are in favour of a short distance – right along the border (r).

		Many filled --> vfr				
		No wind (nw)	Moderate w. (mw)	Medium w. (mw)	Strong w. (sw)	Very strong w. (vsw)
Risk	No - empty (n)	S	S	S	S	S
	Low (l)	vfr r	vfr r	vfr qf	vfr qf	vfr qf
	Medium (m)	vfr r	vfr qf	vfr qf	vfr f	vfr f
	High (h)	vfr f	vfr f	vfr f	vfr f	vfr f

Fig. 4. **Decision-making table**

It means that the elements of the first diagonal and their surroundings are easily filled, but the most ambiguous ones are the elements around the second diagonal where the large values of one criterion meet the small values of the second criterion. It suggests that elements can have mean values, e.g., qf – quite far away. It is based on the following logic. A decision has to be made taking into account the most dangerous gradations of a criterion, but the small values of the other criterion reduce this level of risk, compared to the situation when both criteria have large values.

A Case with Conditional Criteria

A typical example of the situation is the inverted pendulum on a moving cart [1]. Let us look at two examples. In the first situation, the pendulum can fall only to the right side. Let us assume that the movement to the right side, the right angle and the angular speed to the right side are all positive values. The methodology of filling the table is similar to the situation with the matching criteria, Fig. 5.

		Pendulum angle α			
		small	average	large	very large
Angular speed Vα	small	small	small	average	?
	average	small	average	?	large
	large	average	?	large	very large
	very large	?	large	very large	very large

Fig. 5. **Decision-making table for inverted pendulum**

Here the filling of the table in the first diagonal and around it is relatively clear: in the top left corner there are the low values of the cart speed, in the bottom right corner – the high and very high values. In the middle section of the diagonal there are the average values. The values of the second diagonal are the most ambiguous ones.

Conclusions

1. It is rational to start the foundation of a production rules based knowledge base with the table form. Only the table form allows seeing the full set of production rules, i.e. a full set of results, ensured neither by the form of "if-then" nor by decision trees.
2. Foundation of the set of all the production rules must be done on the basis of the formal regularities.
3. These formal laws are not the same in all cases. They depend on the nature and type of the decision criteria.
4. Decision criteria can be mutually exclusive, independent, matching, dependant etc.
5. It is beneficial to start the filling of the table of production rules with the cells which can certainly be filled. It allows isolating the ambiguous cells, which have to be filled with specific methods.
6. In the fuzzy decision-making process for the ambiguous cells, one can use:
   - different existing ratios of importance;
   - priorities of criteria defined by knowledge engineers;
   - logical connections and charts created by the knowledge engineer;
   - evaluations and decisions of a group of experts, taking into account the experiment conditions etc.

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