One fuzzy hierarchical algorithm for mobile robot navigation

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Introduction

In most cases, fuzzy rule base is designed to fulfil a single control policy or goal. In order to achieve autonomy, mobile robots must be capable of achieving multiple goals whose priority may change with time [4]. Therefore algorithms should be designed to realise a number of task-achieving behaviours that can be integrated in order to perform different control objectives. This requires formulation of a large and complex set of fuzzy rules. In this situation a potential limitation of monolithic fuzzy controllers become apparent. Since the size of complete monolithic rule base increases exponentially with the number of input variables [6], multi-input one-layer systems are potentially inappropriate for real-time response systems. Hierarchical rule structure can be employed to overcome this limitation by reducing the rate of rule increase to linear. The following paper describes one such algorithm.

Algorithm

Here an algorithm based on a behavioural model of mobile robot navigation is described [1]. It presents one different idea for hierarchical organisation of fuzzy rules, compared to [2], [7] and aims at a practical realisation of multi-stage fuzzy inference process onto single-stage hardware fuzzy controllers. Fuzzy behaviours are synthesised as fuzzy rule-base, i.e. a collection of finite set of fuzzy if-then rules. Every behaviour is implemented into one Fuzzy Logic Control Block (FLCB) (Fig. 1) that has an independent rule base, designed for particular input and output.

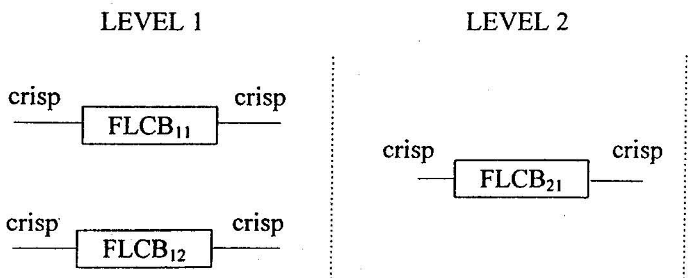

Fig. 1

Proposed is a bottom-up hierarchy of increasing behavioural complexity. Activity at a given level is dependent upon behaviours at the level(s) before.

The first level processes sensor information. It is the most 'primitive' level, which aims at detecting input and making reactive (non-intelligent decisions). However it determines the perceptive base of the robot – more different type of sensors means better evaluation of surrounding world.

Second level unites the results from previous level in order to achieve more intelligent tasks. All behaviours are taking part in the overall inference process, instead to only one as it is in arbiter approach, for example. At every level we have crisp input and output from FLCB so we don't have real propagation of fuzzy truth values. Separate results from separate inference processes are united by a new inference process. That is only possible if the output universe of discourse of the first level behaviours is equivalent to the input universe of discourse of the next level.

The advantages of this architecture are:

- The hierarchy facilities decomposition of complex problems.
- Increased run-time efficiency by avoiding the need to evaluate rules from behaviours that are not active, i.e. those which are not activated by input sensor information.
- Flexibility: Every $FLCB_{ij}$ can be regarded as an independent and therefore replaceable unit. That means that we are able to change the model of the system simply by replacing one FLCB with another one with different parameters. It is also possible to built in every FLCB an opportunity for internal block extension. For example, FLCB could contain a rule base for n inputs but it could also process any number of inputs between 1and n.

Synthesis of the algorithm

The easiest way to describe synthesis of the algorithm is to use an object like Rug Warrior [4] and to build the model of the robot. It is a small mobile robot with 2-wheel differential drive and one stabilising caster. It is with oval shape, 20 cm tall and 10 cm radius. The sensor base includes all sensors shown on Fig. 2. It includes different types of sensors and their placement onto the robot according to the surrounding environment. Choice of sensors depends from concrete tasks we want to settle for the robot.

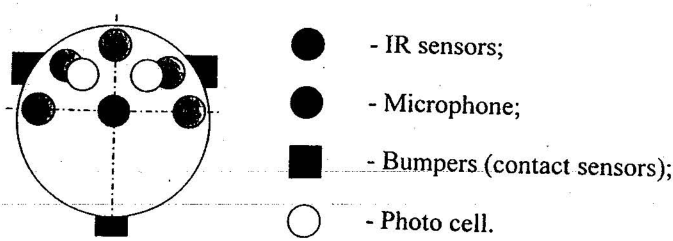

Fig. 2

For example, it should have IR sensors for distance determination, photo sensors (photo cells) for light level detection, microphone for sound detection and so on.
Next step is the description of primitive behaviours. This includes the whole procedure for FLCB description. Simple, first level behaviours cannot be used alone to control for executing parts (motors, actuators, and so on.). At least one second level behaviour should be active for proper work. An example hierarchy is presented on Fig. 3. It includes two first level behaviours and one second level.

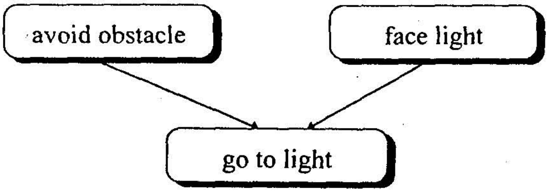

Fig. 3

The first level includes two behaviours *avoid obstacle* and *face light*, consequently two independent FLCB. Behaviour *avoid obstacle* is based on five IR sensors. For obstacle position the difference between two consecutive sensor readings is used. Results could be converted into linguistic variables on one and the same universe of discourse as all represent information of one and the same type and range. Full description of the FLCB [5] responsible for that behaviour includes:

- Definition of the parameters of the FLCB: type of fuzzy inference process, types of fuzzification and defuzzification procedures;
- Definition of input and output process variables and conversion into appropriate universe of discourse;
- Membership function (MF) determination. That means choice of shape, number of sets, global range and range of every single MF;
- Rule base definition.

In the same way we describe *face light* behaviour and second level one *go to light*.
We are able to extend the algorithm by including new types of sensors and organising information into simple and complex behaviours. Communication between behaviours is important as they should be able to suppress, inhibit or modify other behaviours. Communication exists only between one and the same level FLCBs (behaviours).

Fig. 4 shows an example of high hierarchy:
It should be mentioned that decomposition into behaviours for a given mobile robot system is not unique. It is subject of analysis of the system and task environment.

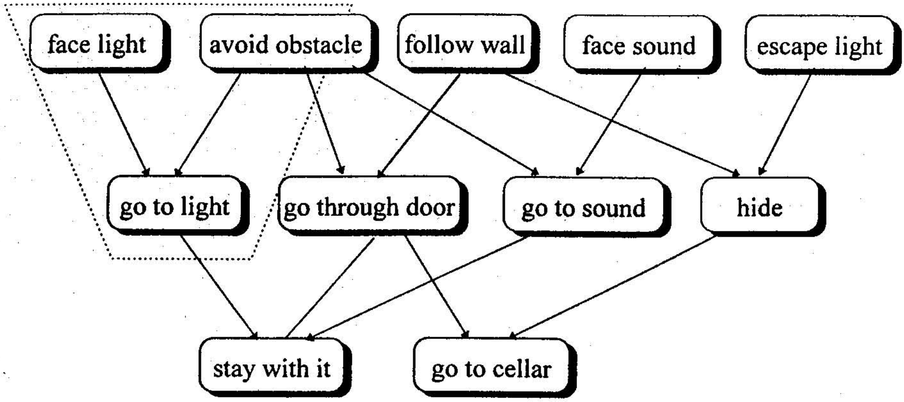

Fig. 4

Navigation example

Verification of described algorithm is done with Robosim3 – a MatLab program for simulation of movement of mobile robots in an artificial environment (Fig. 5). It uses Ray Tracing method for obstacle and target position determination. Fuzzy calculations are done with MatLab Fuzzy Toolbox.
Simulated world is hypothetical indoor environment. We can set the initial coordinates of the robot and the target (in this case that is source of light).

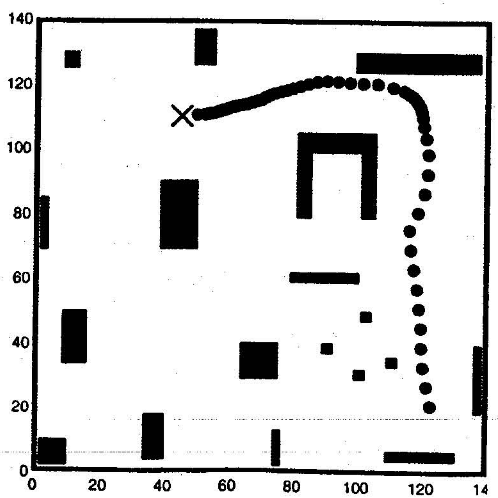

Fig. 5

Avoid obstacle merely displays cyclic collision-free movement in the immediate vicinity of the robot initial location. *Face light* on the other hand, forces the robot to rotate in such fashion that the strongest light source to be always in front.

Conclusions

The hierarchy of fuzzy behaviours provides an efficient approach to controlling mobile robots. The decomposition of overall behaviour into sub-behaviours which are active only if set by the concrete task. The flexibility and modularity of the approach make it suitable for modelling and controlling navigation of autonomous robots. To date, simulations are used to predict the performance of a real robot and a hardware system is under construction.

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