CONTROL SYSTEM BASED ON THE HYBRID EXPERT SYSTEM COMBINING THE PRODUCTION RULES AND LINGUISTIC VARIABLES

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Abstract
For control of any system it is needed to consider different situations at which the controlling mechanism works. A situation is formed and defined on the set of probable states of the object to be controlled and on the set of probable interactions of the object with its environment in the outer world./ 1 /. The first segment of the situation consists of the accurate information. However, internal and the external characteristics of the object remain mostly as inaccurate information. Therefore, in the proposed controlling system based on the Hybrid Expert System (HES), in the first level we will consider the existence or absence of the object or change of the environment of the object and in the second level of the HES we consider the internal and external characteristics of the object i.e. parameters of the object itself. Since the object always exists with all its inherent characteristics i.e. parameters, in the process of defining the parameters, all the rules relating the object with its environment do not change substantially / 2 /.

1. Working Principle of the HES. Let us consider the joint operation of the two levels of the HES. When the first level works on the basis of the rules of the Knowledge Base (KB) K_1, the second level supplies to K_1 information for achieving the required goal taking into consideration the technical possibilities of the first level. The technical system should work accordingly. For this purpose it is needed to form additional rules for change of the environment in the K_1 related to the solution of the second level depending on the technical realization of the first level.

For representation and processing of knowledge with HES in the first level is used the Production Model of Knowledge Representation (PMKR) / 3 / and in the second level is used the Linguistic Model of Knowledge Representation (LMKR) / 4 / . The PMKR is used when the rules and the environment are known accurately so that with their help any change in the environment can be determined. These rules can be deterministic as well as stochastic. However, the LMKR is used when data about the environment and rules about how these data are changed are not accurately known. For the proposed HES, the LMKR is used for considering the parameters of the object to be handled by the robot. For both the levels are formed different databases (DB) F_1 and F_2. Integration of both the levels demand processing of the algorithm for their combined operation.

Let us consider the integrated HES,

$$HES = < F_1, F_2, K_1, K_2, I_1, I_2, C_1, C_2, < g_1^1, g_2^1, g_3^1, ..., g_n^1 >, < g_1^2, g_2^2, g_3^2, ..., g_n^2 >$$

where

F_1 and F_2 – data bases of the first level and second level respectively;
K_1 and K_2 – knowledge bases of the first level and second levels respectively;
I_1 – Interpreter of the rules of the first level;
I_2 – Mechanism of knowledge processing of the second level;
C_1 and C_2 – demands of the first and second levels respectively;
$< g_1^1, g_2^1, g_3^1, ..., g_n^1 >$ – sub-goals of the first level;

$< g_1^2, g_2^2, g_3^2, \ldots, g_n^2 >$ – sub-goals of the second level.

The data base F which represents the current situation of the HES, can be written as $F = F_1 + F_2$

$F_1 = \{C_1, E_1\}$, where C_1 and E_1 are expressed as the L-times operation of the conditional change of the situation S. The conditional change can be represented as follows:

S Prod^P = (...((S Prod P_{Y1D1})Prod P_{Y2D2})...)Prod P_{YLDL}, where Y and D are the conditions and decisions of the rules P respectively / 5 /.

S Prod^P – production of the rule.

$F_2 = \{C_2, E_2\}$, where C_2, and E_2 are determined in the following way:

$$C_2 = S_r(v_r^i \mid \mu_r^i), \forall v_r^i \in V_r, \forall s_r^i \in S_r,$$

where

S_r – set of r parameters of the object, which the must take into consideration; V_r – subset of the evaluation of the data received from the sensors, which correspond to the parameter r;

μ_r^i – inclusion function shown by the i-th sensor related to r-th parameter.

$$E_2 = (d_i \mid \mu_d^i), \forall d_i \in D_2,$$

where

D_2 – subset of the decision taken in the second level of the expected action of the HES;

μ_d^i – inclusion function which correspond to the element of decision d_i.

Knowledge base K_1 of the first level of the proposed HES is written as the expression / 7 /

$$K_1 = \{\underset{\sim}{Y}, \underset{\sim}{D}, \underset{\sim}{P_Y}, \underset{\sim}{P_D}, P_{YD}\}$$

where

$Y = (y \mid \mu_y), \forall y \in Y$ – fuzzy subset which we call as the condition for application of the rule;

$D = (d \mid \mu_d), \forall d \in D$ – fuzzy subset of the action which in the process of production of the rules are brought into the data base and through the effectors change situation of the environment;

P_Y, P_D, P_{YD} – fuzzy relations given corresponding to the intersections of the sets S×Y, D×S, Y×D. We shall use the traditional form of expressing the rules through facts

P_{YD}: IF $(f(y) \mid \forall y \in Y)$ THEN $(f(d) \mid \forall d \in D)$

For the coordination of the action of the second level of the HES, conditions and correspondingly actions are increased in the rules of the KB of the first level K_1 of the HES. However, due to this the power of the K_1 remains unchanged. The Knowledge Base K_2 contains the composition rule of decision , concept matrix E_r for the different parameters under consideration, S_r - matrix of the final or goal decision, priority vector and the matrix of the concept "ACTION" D. Interpreter of the rule I_1 of the first level remains unchanged. However, for the solution of the given task for achieving the goal it is needed to satisfy the additional conditions with the help of the processing mechanism of the second level of the HES I_2.

Let at the moment of T_i the HES start working. For the realization of the global production, it is needed to perform the operation of the change of the fuzzy subset S represented by the DB at this moment of time. Since the DB of the given HES is divided into two different levels, their situational conditions are also different at the same time. Let us denote them as S_{i1} and S_{i2} respectively, where the index i denotes the situation at the moment T_i.

As it was mentioned, that for the DB of the first level of the HES would be applied the production rule of decision. The state S_i changes with time along with application of the relation

S Prod P_{YD} = ChC_{YD} S

L – times for the achievement of the sub-goal of the first level / 5 /.

The state S_{i2} i.e. the DB of the second level of the HES changes only with the appearance or disappearance of the object with the help of composition rule of decision.

Let the environment in the given SPS be represented at the initial moment of time in the data base F_1 controlling HES by the situation S_{01}. As soon as the object appears in the SPS in the next moment of time, the environment changes accordingly and the situation is changed taking into consideration the parameters of the appeared object. Let us represent the fragment of the situation which is changed due to the appearance of the object as S_{02}. Then the complete representation of the situation can be expressed as $S_{0C} = \{S_{01}, S_{02}\}$. Since the situation S_{02} is determined by the change in the environment taking the parameters of the object into consideration, it creates the data base of the second level of the HES i.e. F_2. However, any change in the environment requires determination of the laws of change in the SPS / 6 /. Therefore it is needed to extend the model of the environment.

Let the fuzzy subset of the laws related with the change in the situation S_{02} be represented by ZY. Then the set of the laws of changes ZT in the environment of the HES be expressed as follows:

$ZT = ZX + ZY$,

where

ZX – subset of the laws of changes in the environment of the first level of HES.

Subset of the laws ZY is related with the environment with rules. However, these rules will not be represented by the production rules only, because the second level of the HES works on LMKR. As it is stated that the change in the environment i.e. in the situation occurs due to the second level of the HES under the actions of the composition rules.

From the above mentioned we can write formally the process of transformation from the situation S_i to the situation S_{i++} in the HES in the following way:

1. $S_i = S_{i1} + S_{i2}$,
2. $S_{i+} = S_{i1}$ Prod $P_{YD} + M[S_{i2}]$,
3. $E_+ = G[S_{i+}]$,
4. $E_{++} = ZT\ [E_+]$,
5. $S_{i++} = G\ [E_{++}]$,

where

G – ordinary relation given in the intersection E×S;

G^{-1} – reverse relation;

$G[S]$, $G^{-1}[S]$ – fuzzy subset induced by the by the relations G, G^{-1}, respectively;

$M[S]$ – reflection of the situation on the set of different concepts in the KB of the second level K_2 with the help of composition rules.

Since the demand and goal of the HES remain unchanged as the demand and goal of the first level determined earlier, rules which connect environment with the subset ZX for achieving this goal also remain effective. However, in this regard some of the elements or conditions and actions of the rules are needed to be changed due to the change of the action of the second level of the HES.

Actions of the second level also depend on the solutions of some problems. In order to solve these problems, it is needed to form the demand and goal of the solution of the problems of the second level, which can be named as intermediate. Let us denote D_2 and G_2 as the demand and goal of the second level respectively which are actually subsets of the intermediate demands and goals of the second level of the HES. In this way we can write:

$D_2 \subset D$ and $G_2 \subset G$,

where

D and G are the demands and goals of the given HES.

With the help of the mechanism of knowledge processing I_2 of the second level of the HES the intermediate problems of the second level can be solved. The demands and goals of these intermediate problems can be represented in the following way:

d_1^2 = reflection of situation S_{02} on the linguistic concept of the parameters of the object;

g_1^2 = linguistic representation of the situation S_{02};

d_2^2 = reflection of the linguistic values of the situation S_{02} on the concept of decision;

g_2^2 = decisions in correspondence with different parameters of the object;

d_3^2 = reflection of the priority vector on the decision matrix;

g_3^2 = vector for the final decision;

d_4^2 = reflection of the final vector for decision on the vector for linguistic values of the decision;

g_4^2 = vector for linguistic values of the decision;

d_5^2 = reflection of the vector for linguistic values of decision on the decision matrix;

g_5^2 = vector for command of action of the second level of HES.

After achieving the sub-goal d_4^2, the situation S_{0C} changes and the under the actions of the laws ZT the sub-goal starts working along with the actions of the first level of HES. Actions of any kind of stochastic rules during the changes in situation in the second level of the HES do not occur because the second level of HES starts working only when the object appears and does not take into consideration any kind of accidental parameters of the object in the given HES.

The solution of the problem of the HES D -----> G* will be found with the help of ordering the sets of the states of the data base DB related with the production of the first and second levels of HES by the correct rules.

TR [D ---> G*] = <S_{0C}, S_1, S_2, ... , S_k>, so that S_{0C} = D; S_k = G*

S_{i+} = ZT[S_i Prod Py_i d_i + M [S_{02}]].

2. Example of application of the HES in the functon of a robot for capturing an object on the conveyer belt in an industrial production system. Let us assume that a robotised system (RS) is controlled by the proposed HES. The purpose of the RS is to capture an object, which will appear on the predetermined place on the conveyer belt and to shift the object to another place after its proper processing. Since the objects can be of different characteristics, the RS must consider these characteristics in seizing this object. For the achievement of this goal, it is divided into different sub-goals. To seize the object with proper force as the goal, it is needed to form the sub-goals by considering different characteristics of the object before seizing the object. While in the first level of the given HES the proper process for seizing the object as the achievement of the goal is realized, in the second level of the given HES the achievement of the intermediate sub-goals is realized.

Let us form the KB for the given HES. At first we have to form the DB for the given HES. The DB of the first level F_1 of the HES can be formed in the following way:

C_1 = left, right, up down, stretched, withdrawn, opened, closed, press-operation-finished, feed-operation-finished, object-in-work-place, object-in-left-arm, object-in-right-arm, object-in-basket;

E_1 = to-left, to-right, upward, downward, stretch, withdraw, open, close, ready, transport-on.

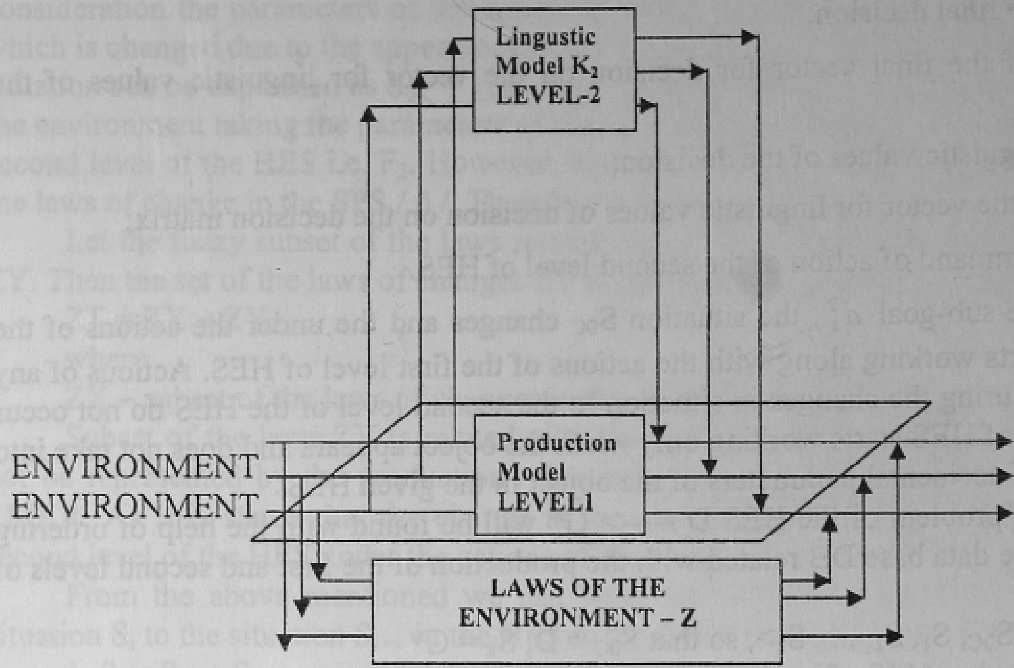
The DB of the second level of the HES will be as follows:

C_2 = set of linguistic variables S_{weight}, $S_{surface}$, $S_{hardness}$, S_{force}, applied-force;

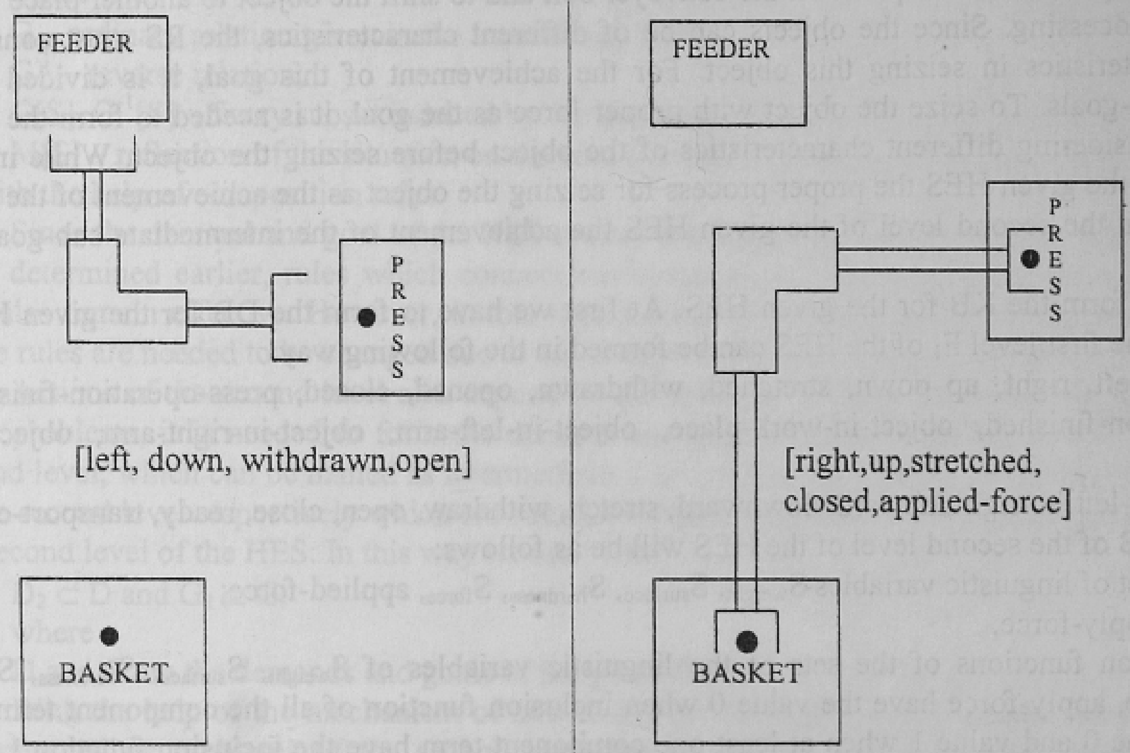
E_2 = apply-force.

Inclusion functions of the sets of the linguistic variables of S_{weight}, $S_{surface}$, $S_{hardness}$, S_{force}, applied-force, apply-force have the value 0 when inclusion function of all the component terms of them have the 0 and value 1 when at least one component term have the inclusion function 1. Let the given RS at the moment of the starting time when the object is still not in the working place be in the following situation:

S_{01} = {left | 1, right | 0, down | 1, up | 0, stretched | 0, withdrawn | 1, open | 1, closed | 0, press-operation -finished | 0, feed-operation-finished | 0, object-in-workplace | 0, object-in-left-arm | 0, object-in-right-arm | 0, object-in-basket | 0, to-left | 0, to-right | 0, upward | 0, downward | 0, withdrawn | 0, stretched | 0, open | 0, close | 0, ready | 0, S_{weight} | 0, $S_{surface}$ | 0, $S_{hardness}$ | 0, S_{force} | 0, apply-force | 0, applied-force | 0, transport-on | 0 }.



Pic-1 Working principle of the proposed HES



Pic2- Positions of the arms

Let the data C_2 be given either from the sensors or from the external DB at the moment when the situation with "feed-operation-finished | 1" occurs. Let this fragment of situation be represented by $S_{02} = \{S_{weight}, S_{surface}, S_{hardness}\}$.Then the complete situation is represented by $S_{0C} = \{ S_{01}, S_{02}\}$.

Let us extend the model of the environment with the help of the following laws reflecting the above mentioned statements:

ZY1: A- = {left | 1,down | 1, stretched | 1, open | 1, feed-operation-finished | 1};

A+ = {press-operation-finished | 1, object-in-workplace | 1, S_{weight} | 1, $S_{surface}$ | 1, $S_{hardness}$ | 1};

ZY2: A- = {left | 1, down | 1, stretched | 1, open | 1, press-operation-finished | 1, feed-operation-finished | 1, object-in-workplace | 1, close | 1, S_{weight} | 1, $S_{surface}$ | 1, $S_{hardness}$ | 1, apply-force | 1 };

A+ = {applied-force |1, apply-force | 1};

ZY3: A- = {object-in-workplace | 0 };

A+ = {S_{weight} | 0, $S_{surface}$ | 0, $S_{hardness}$ | 0, apply-force | 0 };

ZY4: A- = { right | 1, down | 1, stretched | 1, closed | 1, open | 1, apply-force | 0};

A+ = {applied-forced | 0 }.

For the coordination of the works of both the levels of HES the following rule is introduced:

IF {left | 1, down | 1, stretched | 1, open | 1, press-operation-finished | 1, feed-operation-finished | 1, object-in-workplace | 1, applied-force | 1}

THEN {close | 1, apply-force | 1}.

In this situation although "apply-force | 1" is included, the amount of force to be applied for the seizing of the object is determined by the KB_2 of the second level of the HES. Similarly at different situations, different amount of force will be applied for seizing of the object according to the decision of the second level of the HES.

Conclusion

Since knowledge is mostly a combination of the accurate information and fuzzy information, the proposed model gives an opportunity to combine them and take the decision accordingly. The proposed model was applied on the model robot in the computer and was found to work perfectly.

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