Fuzzy Control of an Inverted Pendulum Based on Emotional Masking and Attention Control

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***Abstract*— The model of emotional masks is a newly developed AI paradigm based on Minsky's model of emotional mind in his recent book "The emotion machine". The model takes a resource management approach toward modeling the mind and views different processes of mind as resources that need to be managed. The idea here is to develop an intelligent controller based on the model of emotional masks to focus the attention of the controller by managing resources available in a controlling action.**

Keywords—Adaptive Control, Emotions, Intelligent Control, Learning

I. INTRODUCTION

We go through loads of emotional states during our lives and experience their different consequent physical and mental patterns. These experiences make emotion a term that we are all familiar with, but implementation of emotions in machines is not that sensible to us. Scientists from all around the world have proved that this is possible and can be an efficient approach if the machine must have the ability of planning or if it faces unknown environments. This is the case of some kind of robots, artifacts, virtual agents, and specially, control algorithms; they should be adaptable to support the uncertainty of some conditions of the controlled process or faults inside the system [1].

Emotions have been a topic of research for a long time among the academia, including different branches of human science and more recently Artificial Intelligence (AI). Different theories explaining emotional behavior of humans and some models for simulation of emotions in machines have been proposed. Among these models a computational model of Amygdala is developed in [2]. In this model authors have focused on the brain structure and tried to model the neural structures within which emotion generation and management are believed to take place rather than the causes of emotion arousal or emotions' basic attributes [5]. This model has been the basis for development of a controller which is called BELBIC (Brain Emotional Learning Based Intelligent Controller) and is explained in [3]. This controller uses two sets of neurons to model Amygdala and the Orbito-frontal cortex. The number of neurons is the same as the number of sensory inputs except for the Amygdala that has an extra neuron which receives the maximum of the inputs. There is a weight associated with each neuron. There is also a stress signal which plays the role of a criterion for adjusting the weights. In such models, only the usefulness of model in promoting control mechanisms in agents is studied and evaluated and sometimes the authors call their model an "emotional controller" or "emotional learning mechanism" without trying to prove the existence of a correct mapping between what we know as emotion and what their model presents [5]. A review of some other emotional models used for the purpose of control is presented in [1].

In [4] Harati Zadeh et al. have argued that in the currently used method of importing a subset of human emotional states into the target artificial system, the major differences between natural and artificial domain is ignored. They have mentioned four main problems existing due to the current method of definition of emotions as: 1-Human's emotional states are modeled based on high level concepts that are not definable in simple systems; 2-Usually the core of emotional system is defined directly by the designer, and usually the system is not able to learn or adjust these hardcode mechanisms; 3-The emotion mechanisms defined in such a way usually play the role of heuristic solutions for specific problems and therefore, are extremely dependent to the knowledge of the designer about the details of the problems that the system may face and their possible solutions; and 4-Hardcode emotion definition avoids the systems from forming their own emotional identities and personalities. In this work they have proposed an abstract model for developing emotional systems which would probably overcome the aforementioned problems.

In another work [5], the same authors have presented a new computational model of emotions. To do so they have introduced a model of emotions based on managing mental resources. They argue that emotions have the role of management of resources available to the mind, therefore performing a masking role regarding the resources. Active resources are specified based on the emotional state of the system, so emotions are somewhat like windows form which the system views its resources. This model is named the model of emotional masks. They have implemented their model in an artificial life simulation environment to evaluate its ability for producing emotional behavior and making better decisions and the results have accorded their theory.

The term attention control was firstly introduced in psychology and then made its way to technological literature by the development of computer vision systems, these systems are confronted with the problem of selecting the salient information out of a vast flow of data. In humans, by directing the high order processing only to some selected parts of a scene, a very fast processing is achieved. This kind of attention mechanism has been integrated in computer vision systems [6]. Attention control in fact solves the information bottleneck problem and makes a useful input sensory space out of a rather distracting one. Reference [7] is a typical work in this field in which authors have proposed a behaviorally active neural mechanism for attention control and pattern categorization which are developed as the basis for robot cognition.

In this work we firstly explain what is believed to be the roles of emotions in mind and then we introduce the emotional masking philosophy. In part IV a nonlinear plant is considered and our approach for controlling the plant is introduced in part V. In part VI simulation results are given and discussed. Part VII concludes this paper.

II. Roles of Emotions in Mind Cognition [8]

There are several theories regarding the role that emotions play in our mind each of which views emotions from certain aspects that seem to be namely:

A. Control of attention

Emotions influence perception and orient reasoning by focusing the agent's attention on the most relevant features to solve its immediate problem. In particular, they have been attributed the role of interrupting the agent from what it is doing when new problems arise that need to be attended to.

B. Source of Reinforcement

Emotions are usually associated with either pleasant or unpleasant feelings that can act as reinforcement. This allows emotions to motivate the agent to approach or avoid certain emotional scenarios. It is often assumed that human decision making consists of the maximization of positive emotions and minimization of negative emotions.

C. Memory Filters

Memory Filters allow better recall of events that are congruent with current emotional state or events that were learned while the agent was in a congruent emotional state. This preferential recall of some events over others can affect the decision making process by making the agent more or less optimistic depending on whether it is happy or sad, respectively.

D. Assistance in Reasoning

The agent's affective system quickly obtains perceptual cues that can be used to direct the access of the cognitive information relevant for the cognitive system's deliberation.

E. Behavior Tendencies

Behavior tendencies or even stereotyped responses are usually associated with particular emotional scenarios. These built-in responses allow for appropriate behavior to be automatically triggered in emergency situations, avoiding spending unavailable time on elaborate reasoning.

F. Physiological Arousal of the Body

A strong emotion is usually associated with a general release of energy in anticipation of demanding action response. The translation of this feature to an artificial system can consist in the modulation of system parameters, such as the level of behavioral activity or speed, which are directly relevant to the overall performance of the system.

G. Support for Social Interactions

The expression of emotions allows the individuals to transmit to others messages that are often crucial to their survival and therefore have great adaptive value.

III. Emotional Masks: Resource management

Minsky in his latest book [10] views the mind as a cloud of resources. This could mean that the mind consists of different parts, each of which has skilled a particular type of duty; so actually the mind could be called a collection of processes or resources.

He believes that resources are any kind of structures or processes from sensory devices to the thinking methods [9]. This type of viewing the mind suggests that not all the resources of mind are always active. So there comes an active part of the mind which is called the working memory. Processes and data are put in the working memory to be processed. Working memory has a limited capacity which can modify the information.

Minsky's model (cloud of resources) can be assumed as the collection of all data and processes of mind and an activation pattern that can perform the role of putting a subset of these resources in the working memory. So an emotional state is nothing but a state of mind (a special structure of data and processes in mind) along with a feeling experience.

A possible justification of this view is that we encounter loads of situations during lifetime. We cannot memorize all these situations with details, but some of these conditions that are important or frequent or need immediate action could be classified in some categories. These categories or classes need to be memorized so that dealing with these situations can be done easily and in a timely fashion.

The way LeDoux views emotions can be the key to modeling the emotional mind of Minsky. LeDoux classifies the emotional processings in two categories: conscious and unconscious. The unconscious part is in charge of activating emotions. This involves directing attention and activating the related knowledge and modifying the contents of the working memory.

So an emotional mind model based on the Minsky's theory can be divided in two parts:

- An assessment and categorization mechanism for the activation of a proper combination of resources (emotional activation mechanism)
- A collection of combination of resources among which the proper structure of mind for facing a situation is chosen.

In this way of modeling in the presence of an emotion, certain resources are activated while other resources are inactive. It can be viewed as:

The mind is looking at its resources through a mask which is changed as the emotion changes.

Accordingly this model is called the model of emotional masks.

In simples systems the only resources available to the system are inputs and probably a knowledge base but in more complicated systems there are also goals, values, programs and needs. So emotional masks in simple systems include only inputs and the knowledge base but in more complicated systems they can also include goals, values...

IV. Inverted Pendulum

The inverted pendulum [15, 16, and 17] system is a standard problem in the area of control systems. The system is nonlinear so it is useful in illustrating some ideas in the nonlinear control field.

The inverted pendulum system inherently has two equilibria, one of which is stable while the other is unstable. The stable equilibrium corresponds to a state in which the pendulum is pointing downwards. In the absence of any control force, the system will naturally return to this state. The stable equilibrium requires no control input to be achieved and, thus, is uninteresting from a control perspective. The unstable equilibrium corresponds to a state in which the pendulum points strictly upwards and, thus, requires a control force to maintain this position. The basic control objective of the inverted pendulum problem is to maintain the unstable equilibrium position when the pendulum initially starts in an upright position. A schematic of the inverted pendulum system is shown in figure 1.

Assuming:

M	mass of the cart	0.5 kg
m	mass of the pendulum	0.2 kg
b	friction of the cart	0.1 N/m/sec
l	length to pendulum center of mass	0.3 m
I	inertia of the pendulum	0.006 kg*m^2
F	force applied to the cart	
x	cart position coordinate	
theta	pendulum angle from vertical	

By drawing the free body diagram of the system (figure 1) and doing a force and momentum analysis the system equation setup can be derived:

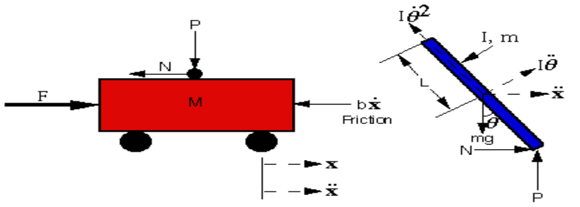

Figure 1. FBD of the system

Newton's equations for the two degrees of freedom:

$$\frac{d^2x}{dt^2} = \frac{1}{M}\sum_{cart} F_x = \frac{1}{M}\left(F - N - b\frac{dx}{dt}\right)$$

$$\frac{d^2\theta}{dt^2} = \frac{1}{I}\sum_{pend} \tau = \frac{1}{I}\left(NL\cos(\theta) + PL\sin(\theta)\right)$$

While the interaction forces are given by pendulum x and y equations:

$$m\frac{d^2x_p}{dt^2} = \sum_{pend} F_x = N$$

$$\Longrightarrow N = m\frac{d^2x_p}{dt^2}$$

$$m\frac{d^2y_p}{dt^2} = \sum_{pend} F_y = P - mg$$

$$\Longrightarrow P = m\left(\frac{d^2y_p}{dt^2} + g\right)$$

V. Controlling Approach

Based on the model of emotional masks there should be two parts in an implementation of such a system including [9]:

- An assessment and categorization mechanism for the activation of a proper combination of resources. (emotional activation mechanism)
- A collection of combination of resources among which the proper structure of mind for facing a situation is chosen.

In simpler control systems such as a fuzzy rule-base the resources of a system can be defined as different parts of the same rule-base. So the controller should learn which resources to activate based on the situation and the performance measure provided. The controller's structure is shown in figure 2:

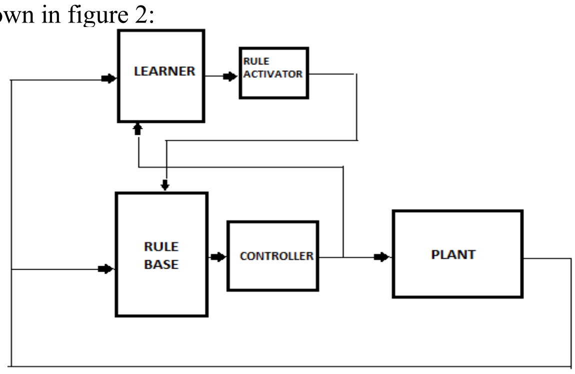

Figure 2. The controller's structure

The controller's core is a fuzzy rule-base which tries to keep the pendulum in an upright position. The learner determines which part of the rule-base should be within reach for the controller, or stated in another way the learner learns to mask the rule-base or choose the related emotion (figure 3).

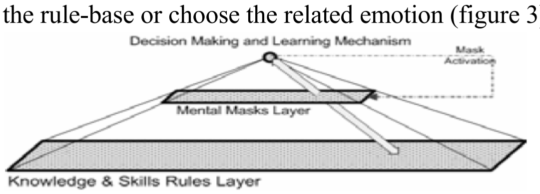

Figure 3. A simple mask [5]

The inputs to the fuzzy controller are the angle error and the derivative of the angle error:

$$e = \theta - 0 = \theta$$

$$\dot{e} = \dot{\theta} - 0 = \dot{\theta}$$

The output of the controller is the force to the cart. Both inputs and the output have 5 membership functions (figure 4) namely Negative Large (NL), Negative Small (NS), Zero (Z), Positive Small (PS), Positive Large (PL).

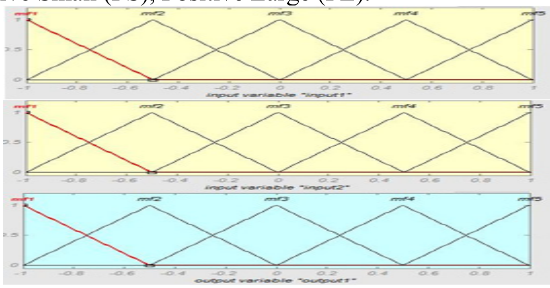

Figure 4. membership functions

Both inputs and the output are normalized for more consistency. The rule-base consists of 25 rules which are shown in table 1.

TABLE I. FUZZY RULE BASE

$\dot{e}\backslash e$	NL	NS	Z	PS	PL
NL	PL	PL	PS	Z	NS
NS	PL	PL	PS	Z	NS
Z	PL	PS	Z	NS	NL
PS	Z	Z	NS	NL	NL
PL	PS	Z	NS	NL	NL

This controller uses a neural net with one hidden layer to serve as the learning mechanism. The performance measure is considered to be the full fuzzy rule-base here for more simplicity in this phase of the work because the stress is put on possibility of implementing the masking mechanism. So the best performance that could be anticipated from this emotional masker is a response close to the response of the full rule-base.

Based on the concepts of an emotional system developed in [4] there is no need for an emotional system to have the same emotions as the humans do. Thus different emotions in this simple system are different parts of the rule-base. The emotional controller tells the system which emotion should be active at each time and these emotions give the system a different point of view toward taking a controlling action.

VI. Simulation Results

The process of putting the emotional masker in charge consists of two steps:

- Training phase
- Control phase

In the training phase the emotional masker is functioning as just an observer for the system and performs no controlling action. It observes the full rule-base controlling the plant and learns how the masking should be done.

To produce enough data for the neural net to mask the rule-base, in the learning phase, a sinusoidal input is fed to the plant. The following figure presents the stabilized plant's response to a sinusoidal input:

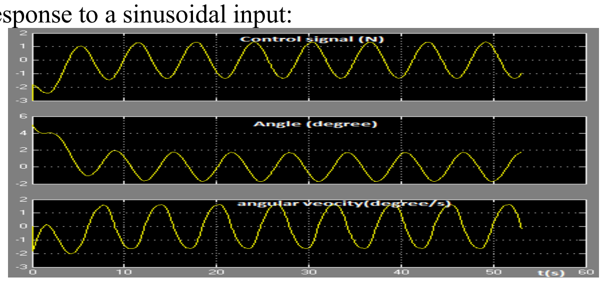

Figure 5. Stabilized plant's response to a sinusoidal input

When the masker learns how to mask the rule-base the control is passed to the emotional masker and the system puts it in charge.

Now that the emotional masker has learned the masking process it is time to put it in charge of the whole system from the beginning of the simulation. The following figure presents this part of the experiment:

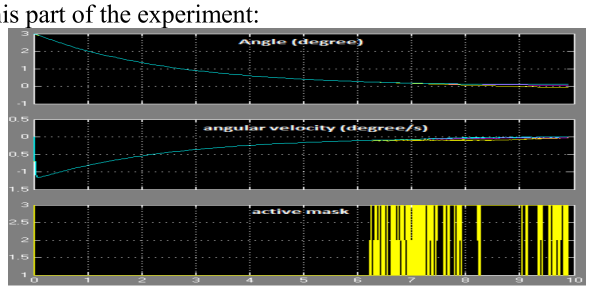

Figure 6. the full rule-base and masker's response

The same figure is shown in the following figure (7) to demonstrate the close to zero part of the same simulation. The experiment is done using a 5 mask system and a 2 mask system. In the following figure number 1 corresponds to the 5-mask system, number 2 corresponds to the full rule-base and number 3 corresponds to the 2-mask system. The performance measure is the same for both states; and it is the closeness of the response of the mask to the response of the full rule-base controller.

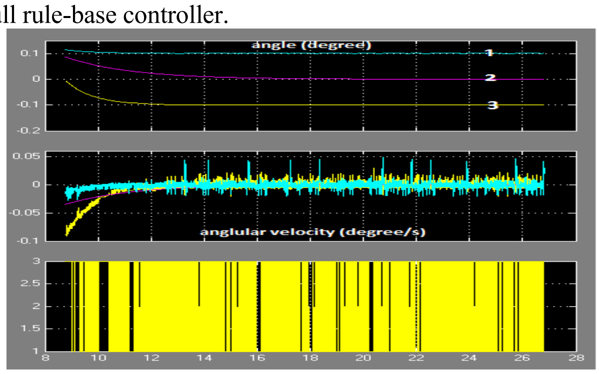

Figure 7. the full rule-base and masker's response (zoom)

As it can be seen from this figure, the controller uses the full rule-base when it is far from the set point (zero). As it gets closer to the set point the emotional masker starts masking the rule-base because in this emotional state that much of computation is not needed and only a part of the rule-base can perform the controlling action.

The other thing that is noticed from these figures is that we are lessening the computation through emotional masks at a price. This price is the steady state error that we can see in the figure. So there is a tradeoff between the steady state error and the amount of computation needed.

For this plant the rule-base consists of only 25 rules which is a rather very small number for a rule-base; But in more advanced systems there are usually thousands of rules in a rule-base; so there is a great deal of computation involved with complicated systems that are not necessary all the time. By introducing emotions to the system by masking rule-bases the heavy computation is done only when it is needed.

VII. Conclusion

The emotional masks model views mind as a collection of processes or resources which are managed using different masks that the mind learns over time. The formulation for an inverted pendulum was presented and the idea of emotional masks was implemented in the control field with a controller on an inverted pendulum. The resources for such a system were considered to be different parts of a fuzzy rule-base defined for the system.

It was shown that while getting close to the set point the masked rule-base (emotions) can perform the controlling action. This is the same as focusing the attention of the controller on a part of the resources of a system. This eliminates the need for the large computation involved with the full rule-base but is done at a price. The price is the steady state error which depends on the performance measure. The performance measure in this part of the work was only the closeness of the response of the emotional masks to the response of the full rule-base controller. So it was normal to expect that the best response of an emotion is one close to the response of the full controller. By using different performance measures it is possible to even get better results than the full rule-base controller.

Putting altogether the main advantage of an emotional masker controller at this phase could be presented as the ability to deal with large rule-bases where a great deal of computation is involved. It reduces the need for large computations by masking the rule-base.

VIII. Future Work

A better performance measure can give the controller more versatility and adaptability through more efficient development of emotions in the system, so the next part of this work focuses on development of a better performance measure for developing emotions.

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