Application Study of Fuzzy ARTMAP Neural Network in Robot Servo System

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Abstract. Robot vision servo control is one of the hotspots in robot research field. However, it is difficult to establish an accurate mathematical model for robot vision servo system. In this paper, a robot visual servo system based on Fuzzy ARTMAP is proposed by using computer vision technology as well as fuzzy theory. After creating a mathematical structure, we present a simulated experiment to verify the performance of this system, which shows the superiority of Fuzzy ARTMAP by comparing it with other traditional visual servo system.

1. Introduction

Robot visual servo is a technique which can indirectly detect the robot's current pose or its relative pose on the target body by using visual sensors and related algorithms. On this basis, robot localization control or trajectory tracking can be realized[1]. It is a new interdisciplinary subject involving neural network, automatic control, real-time system analysis and so on[2]. In recent years, with the rapid development of image processing, pattern recognition and other related fields, the information contained in images has been mined and applied more. The accuracy and reliability of visual servo are improved, which enhances the learning ability of the robot to the surrounding environment and enables it to make intelligent decisions according to the understanding of the environment and accomplish the assigned tasks. But robot vision servo system is a very complicated nonlinear system. First, the robot system itself is a highly nonlinear, strong coupling, time-varying dynamic system, and its control is complex. Because of the inaccuracy of measurement and modeling, the change of load and the influence of external disturbances, the accurate and complete kinematics model of robot can hardly be obtained[3]. In addition, the vision is also a complex sensory. High-complexity algorithms are usually needed to extract the feature information from a large amount of visual data. The video capture equipment such as video camera will also be affected by many factors. Low accuracy, incompatible light intensity and transmission noise make the visual information contain noise inevitably, which increases the difficulty of image processing. At present, the average camera sampling rate is not high. Besides, a plenty of time will be needed to transmit large amounts of visual data. Furthermore, since most image processing algorithm is nonlinear, how to make the complex visual servo system achieve the desired target efficiently depends largely on the selected control strategy.

2. Discussion on Fuzzy ARTMAP
Adaptive Resonance Theory. The adaptive resonance theory network was proposed by Professor Carpenter of Boston University in the United States. Subsequently, Carpenter and his student, Grasberg S., put forward the ART neural network. As a self-organizing clustering algorithm that mimics the cognitive process of human brains, ART has its unique advantages in solving the increasingly complex clustering and classification of large amounts of data in modern times. Its applications include classifying and judging the states of complex systems, implementing data mining and knowledge discovery[4]. ARTMAP can complete real-time learning and adapt to non-stationary environment. The object designed by ART has a stable and fast recognition ability, and it can quickly adapt to the new object which does not learn. The object also has the capability of self-normalization, sometimes as a key feature, sometimes as a noise, depending on the proportion of certain features in the whole. It does not need to know the sample results in advance since it is unsupervised learning[5]. ART's starting point is to draw on people's cognitive processes and the characteristics of brain work. People can categorize and recognize things in a complex, non-stationary, and disturbed environment. This learning is often self-organizing and the accumulation and storage of knowledge are both rigid and flexible, that is, on the one hand, they can firmly preserve what they have learned, and on the other hand, they can learn a lot of new knowledge. The input data and the top-down learning expectation simultaneously perform input to the competition collaboration network, while bottom-up learning is the output of the competition collaboration network. At the same time, bottom-up learning can also be the input of the competition collaboration network while the top-down learning expectation is the output. Real perception can be generated through the studying and matching of this competition collaborative network.

Fuzzy Theory. Fuzzy theory is a mathematical theory, being established by studying and summarizing all kinds of intelligent activities in which human beings use language as media. It is based on fuzzy sets, whose basic spirit is to accept the existence of the phenomenon of ambiguity of facts and to deal with concepts of fuzzy uncertainty. Based on this theory, converting natural language statements or body motions, which are mostly fuzzy, into rigorous quantification data can be easier. Thus, the computer can handle these messages. The membership function was first proposed by professor L.A. Zadeh to express the fuzziness in a complicated system. With the help of the membership function, a fuzzy concept can be expressed as a quantitative representation. The matching of fuzzy concepts refers to the similarity between two fuzzy concepts, and the similarity degree of the two fuzzy concepts is also called the matching degree. There are two basic methods for calculating the matching degree, semantic distance and proximity. When the matching ratio is greater than a given threshold, the matching of the two fuzzy concepts is considered. The semantic distance can also be used to determine whether the two fuzzy concepts match. Generally, a decision could be made by checking if the semantic distance is less than a given threshold. In most cases, shorter distance means more similarities.

Fuzzy ARTMAP Neural Network. Fuzzy ARTMAP neural network combines fuzzy reasoning and self-resonance theory. It has both strong on-line adaptive ability and good class resolution, and it has good operability. By integrating fuzzy theory into ARTMAP dynamical systems, we can realize arbitrary mapping between arbitrary input and output space, so it is suitable for mapping and classification in high dimensional space. It achieves a new minimum maximum learning rule by matching pursuit process. That is, minimizing prediction error and maximizing coding compression rate. The two modules can be divided into the attention subsystem and the orientation subsystem. The attention subsystem for dealing with the mode of learning, fine-tuning will establish accurate internal value to the already familiar pattern representation; orientation subsystem is used for processing the emergence of new mode when there are not familiar with the incident, it pays attention to callback system and set up internal encoding new inside to represent unfamiliar events. Fuzzy ARTMAP is based on the form similarity between the fuzzy subset calculation and the ART neural network class selection method, and combines the advantages of ART and fuzzy logic. The Fuzzy ARTMAP neural network is composed of two Fuzzy ART models. They are ARTa and ARTb, which are connected by Fab. The Fuzzy ARTMAP neural network logic is shown in Figure 1.

3. Robot Servo System Based on Fuzzy ARTMAP Neural Network
Camera Imaging. As the eye of a robot, the camera realizes the transformation from the scene to the image, and realizes the conversion from the three-dimensional scene space to the two-dimensional image space. The camera is fixed on the machine at the end of the arm, the camera coordinate system relative to the manipulator coordinate geometry is fixed, but relative to the working space of the base coordinate system is changed, and this model can accurately see the local scene. The axis coincides with the optical axis of the camera. The robot takes the image of the target ball through the camera and extracts its features to form a closed loop. Fuzzy vision controller is based on the error of image features. According to the rule, fuzzy control obtains the expected change rate of several key joint positions of the robot. Robot visual servo control system is a multi-input multi output nonlinear system dynamics, it has the characteristics of time-varying, strong coupling and nonlinear, it is difficult to find the exact mathematical model, using the traditional control method based on object model is difficult to carry out effective control. In addition, the robot vision servo control system also has serious uncertainty. This uncertainty can be divided into two categories. One is the uncertainty caused by the calibration error of camera parameters. The other is the uncertainty of the dynamic characteristics of the robot itself due to load, friction and other factors. The robot vision servo control method must have strong robustness to these uncertainties. Fuzzy control is mainly based on the operating experience of operators instead of the mathematical model of the object so it is not sensitive to the change of the parameters of the controlled object and can effectively overcome the nonlinear, time-varying, coupling and other factors.

![Figure 1. Fuzzy ARTMAP neural network structure.](image1)

![Figure 2. FTMAF method.](image2)

Up to now, many scholars have proposed different methods motion feature analysis and recognition which apply to different context. In this visual servo system, we use the FTMAF method of [1] to extract the frequency characteristics (i.e. Inter-frame features) of different motions by the correlation
processing of the transform domain, which is showed in Fig 2. In addition, we also combine the
position and Chroma of pixels with their neighborhood features (i.e. Intra-frame features) for the
correlation analysis, and construct three-dimensional vector set I as the input data set for Fuzzy
ARTMAP.

\[ I = \{ i_1, i_2, i_3, \ldots \}, \text{ in which } i_n = \{ freq_n, pos_n, chroma_n \} \quad (1) \]

Design of Fuzzy Vision Controller. The fuzzy controller to the visual sphere in the image plane
of the image features as the input language variable of robot visual servo system, the position of each
joint manipulator is expected to change rate as the output signal corresponding to the output variables.
When the desired value of the target image feature is expressed, the image characteristic value
indicates that the robot hand reaches the target position. This paper sets the expected eigenvalue of the
target. When the target center reaches the center of the imaging plane of the camera and the imaging
radius of the target is small ball radius, it indicates that the robot end gripper reaches the desired
position. The rule is based on the defined input and output language variables, and all possible state
controllers should consider and indicate each of the best actions. The system is now analyzed, the first
joint movement in the imaging plane will change the value of x and r, second and third joint
movement will change the radius of R and Y values.

**Table 1.** Table of fuzzy control rule

| F+ | QF- | N- | VN | N+ | QN+ | F+ |
|----|-----|----|----|----|-----|----|
| B+ | VB+ | VS+ | Z | VS- | VB- | B- |
| QN+ | B+ | VB+ | S+ | Z | S- | VB- | B- |
| N+ | VB+ | VB+ | S+ | Z | S- | VS- | VB- |
| VN | VB+ | VS+ | S+ | Z | S- | VS- | VB- |
| N- | VB+ | VS+ | S+ | Z | S- | VS- | VB- |
| QN- | VB+ | VS+ | S+ | Z | S- | VS- | VB- |

Thus, the fuzzy vision controller determines J based on the values of x and r. Therefore, we can
combine the values of variables x and r to construct a two-dimensional vector set O as the output data
set of Fuzzy ARTMAP. After a series of simple linear operations based on fuzzy theory, the output
vector can directly control the robots precisely.

\[ O = \{ o_1, o_2, o_3, \ldots \}, \text{ in which } o_n = \{ x_n, r_n \} \quad (2) \]

In this paper, we focus on the design and processing flow in Fuzzy ARTMAP instead of
mathematical analysis of fuzzy theory. To design a proper Fuzzy ARTMAP, we need to set some key
parameters first.

\[ \begin{align*}
\alpha & \in (0, +\infty) \\
\beta & \in [0, 1] \\
\rho & \in [0, 1]
\end{align*} \quad \text{ and } \quad \sum_{j=1}^{T} w_j = 1 \quad \sum_{d=1}^{3} w_d = \alpha + \sum_{d=1}^{3} w_d \quad (3) \]

Note that the first parameter α is determined by the dynamics of the ARTMAP, β and ρ is the
learning rate and threshold of the network respectively. Parameter \( w_d \) is the weight coefficient for the
J-th pattern. In order to select the most matching pattern vector in the second layer of the ART
network, we give the selection function as follows.

\[ T_d = \sum_{d=1}^{3} \min(i_d, w_d) \frac{\alpha}{\alpha + \sum_{d=1}^{3} w_d} \quad (4) \]

When the matching degree between input vector and every existing patterns are all less than the
threshold, the system will add a new pattern vector. This mechanism is not only the basis for ensuring
the incremental learning of neural networks, but also the foundation of system self-adaptability. If the
system determines that the input vector matches a certain pattern vector, the weight of the pattern is
updated as follows, making the input vector more compatible with the pattern vector.

\[
\begin{align*}
w_{ij}^{new} &= \beta \cdot \left( \min(\bar{w}^{i}_j, w^{i}_j) \right) + (1 - \beta) \cdot w_{ij}^{old} \\
&= \frac{\beta}{\mu} \cdot \left( \min(\bar{w}^{i}_j, w^{i}_j) \right) + \left( 1 - \frac{\beta}{\mu} \right) \cdot w_{ij}^{old}
\end{align*}
\]  

(5)

If there is a case that a classification is activated in ARTa or ARTb, the mapping domain Fab will be activated. The role of Fab is to contact ARTa and ARTb to perform match tracking. Let event A be “the J-th node F2a being activated”, while the event B “the J-th node F2b being activated”. Then, the output vector \( x_{ab} \) can be calculated by using the following formula.

\[
x_{ab} = \begin{cases} 
\min(y^{a}_j, w^{ab}_j) & \text{if } A \land B \\
\min(y^{b}_j, w^{ab}_j) & \text{if } A \land \neg B \\
y^{b}_j & \text{if } \neg A \land B \\
0 & \text{if } \neg A \land \neg B
\end{cases}
\]

(6)

Simulation Experiments. The experimental simulation results in Fig 3. shows that the visual servo system based on Fuzzy ARTMAP has better performance than ordinary design when target modes are about 10 (set randomly as [10,20] uniform distribution).

![Figure 3. System Accuracy Test with Mode Number Around 15.](image)

Compared with the previous visual servo system, the Fuzzy ARTMAP control system not only performs higher motion recognition accuracy, but also has strong flexibility and scalability. Although neural network is adopted in this system, the average system latency is still low enough, which could be clearly seen in Fig 4.

![Figure 4. System Latency Test with Unfixed Mode Number.](image)

In addition, the increased number of motions results in increased latency and reduced accuracy. However, as Fig 5. shows, even when the number of motion modes is more than 30, the accuracy of the system is still close to 85% which is contrasted with the severe decline of the traditional visual
servo system accuracy.

Figure 5. System Accuracy Test with Unfixed Mode Number.

We can conveniently study the performance of visual servo system based on image moments because some interface of the simulation program have been reserved for the system function expansion, which create favorable conditions for further research on visual servo system.

4. Conclusion
The Fuzzy ARTMAP system designed in this paper is applied to the robot visual servo control. It does not depend on the precise model of the object or the precise motion mode. The control rules come from the rules of users’ daily life. It can figure out many problems caused by the nonlinearity, coupling and time variation of robot vision servo system. To design a robot which have more powerful recognition and processing ability, a Fuzzy ARTMAP program and some basic rules could be enough. System self-learning, scalable features not only ensure the stability of the system, but also provide a method to meet different needs of individual servo systems, which will be the development trend.

Now that the image feature extraction part of the system still costs so much computing resources. Our future work is to simplify the feature recognition model in order to reduce the time complexity as well as ensuring the accuracy.

5. References
[1] G Abebe, A Cavallaro and X Parra 2016 Robust multi-dimensional motion features for first-person vision activity recognition J. Computer Vision & Image Understanding. 149 229-248
[2] Li Zhe 2015 AP Based Neurocomputational Spatial Uncertainty Measures J. Hologrammetric Engineering & Remote Sensing. 74 1573-584
[3] Wang Linglin, Liu Yongxin, Guo Peng and Zhang Hui 2016 Design of Ball Location Control System Using Industrial Robots Based on Computer Vision J. Control Engineering of China. 10 1634-1638
[4] Wang Yongding and Nie Lina 2010 Design of Servo Steering of Intelligent Car Based on Fuzzy Control J. Machinetoool & Hydraulics. 14 75-78
[5] Yang Hui 2014 Design of Frequency Selective Surface Based on Evolving Fuzzy Neural J. Modern Computer. 7 14-17