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An improved cerebellar model articulation controller based on the compound algorithms of credit assignment and optimized smoothness for a three-axis inertially stabilized platform☆

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ABSTRACT

An improved cerebellar model articulation controller (CMAC) based on the compound algorithms of credit assignment (CA) and optimized smoothness (OS) is proposed to improve the control performances of a three-axis inertially stabilized platform (ISP). On the basis of both advantages of CA and OS algorithms, the improved CMAC neural network controller can deal with the disadvantages of conventional CMAC in learning interference and output fluctuation. As a result, the main dynamic performances of the ISP control system are systematically promoted. To verify the method, the simulations and experiments are carried out respectively, in which the LuGre friction model is introduced to represent the main disturbances. The results show that the CA&OS-CMAC controller can efficiently restrain the nonlinear disturbances and obviously improve the ISP's pointing precision and output smoothness. Compared with the conventional CMAC controller, the root-mean-square (RMS) errors of tracking the angular position under the static base swinging and dynamic base leveling conditions are reduced by 17.17% and 30.55%, respectively.

1. Introduction

In an aerial remote sensing system, the Inertially Stabilized Platform (ISP) is responsible for holding and controlling the line of sight (LOS) of the imaging sensors to keep steady in an inertial space, which plays a crucial role for successfully obtaining high accuracy images. Maintaining sensor orientation toward a target is particularly challenging when the imaging sensor is carried on a mobile vehicle or when the target is highly dynamic [1]. In presence of various disturbing phenomena like vibration, turbulence, gust, etc., nonlinear factors will deteriorate the static and dynamic performances of the aerial remote sensing system, such as friction, unbalance torque, dynamic coupling, and so on, which make the ISP control more complex [2]. Therefore, the most critical performance metric for an ISP is torque disturbance rejection.

It is a principal issue for ISP's control system how to minimize the effects of disturbances introduced on ISP [1]. Typically, the ISP might be viewed as a means for removing high-frequency disturbances and controlling the LOS, whereas the pointing and tracking loops have the task of removing the lower frequency parallactic motion and perhaps any bias or drift in the ISP rate loop [3]. In a multi-axis ISP, there are extra nonlinearities that make the stabilization task more difficult. These nonlinearities arise not only from the dynamics of gimbaled system but also from the nonlinear behavior of other disturbances [4]. Therefore, to minimize the effects of multi-source disturbances is the key for ISP to realize high control precision. There are continuous interests for researchers to develop the control methods with higher accuracy and stability by various disturbances rejection [5]. In [4], a three closed-loop PID compound control scheme is applied to a two-axis ISP, in which three closed-loops from inner to outer are current loop, velocity loop and position loop, respectively. Except for the disturbance, another critical factor that influences the control performance of the system is the time delay on the data transmission and data processing. Since various signals are transmitted and processed, in general the time delays and disturbances should be considered during the control system design for a mechatronic system [6]. In [6–10], the stability of linear time invariant (LTI) systems with independent multiple time delays and the cluster treatment of characteristic roots

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(CTCR) paradigm are investigated from a new perspective. However, for the ISP system, since the time delay on the data transmission and data processing are not of paramount importance compared with multi-source disturbances, they are not taken into account to the subject in this paper.

Neural-network (NN)-based control strategy has been widely used in industry fields, such as induction motor control [11,12], multi-axis motion control [13] and irrigation system [14]. NNs are favorable because they have excellent learning capacity, do not require human experience and use a previously known physical model of the system [15]. The most useful property of NNs is their ability to approximate arbitrary linear or nonlinear mapping through learning. Based on their approximation ability, the NNs have been used for approximation of control system dynamics or controllers [16]. For a nonlinear system, NN control can get much more attractive performance and robustness than conventional control methods [17]. However, the general NN control algorithm is more complex, its learning process is long, and parameter convergence speed is slow [18]. To overcome the disadvantages of NNs, the cerebellar model articulation controller (CMAC) [19] was proposed for the identification and control of complex dynamical systems [20]. CMAC is a class of neural network that models the structure and functions of the part of the brain known as cerebellum [21]. CMAC is more suitable for real-time implementation, since it does not contain time-consuming sigmoid-activation functions [22]. Owing to its simple structure, rapid learning speed, insensitivity of data sequence, inexistence of local minimum, and easy hardware implementation, the research on the CMAC has been very extensive [23]. CMAC offers fast training time, guaranteed convergence, and partial generalization [24]. Therefore, the CMAC can be used to approximate a wide variety of nonlinear functions and is widely applied to real time robotic control, signal processing, image coding and pattern recognition [25]. The algorithm is essentially an adaptive table look-up scheme since it can modify the contents in the memory table by using a learning algorithm [26]. Each state variable is quantized and the state space is divided into discrete states. A vector of quantized input values specifies a discrete state and is used to generate addresses for retrieving information from the memory for this state [27]. However, the major drawback of the existing CMACs is that their output weights are constant [28], which influences seriously the studying efficiency and control precision.

In the conventional CMAC leaning schemes, the correcting amounts of errors are equally distributed into all addressed hypercubes. To improve the learning speed of the CMAC, the concept of credibility (confidence) of the studied knowledge was proposed in [30], in which the inverse of leaning times of the addressed hypercubes was used as the credibility of the leaned values. Therefore, the concept of credit assignment (CA) is then proposed that is an updating algorithm requiring the updating effects be proportional to the responsibilities of hypercubes. Since the distributions of errors into the addressed hypercubes of CMAC are not proportional to their credibility, it may cause unacceptable learning performance. The credit-assignment CMAC (CA-CMAC) is therefore proposed which can solve this problem by using the creditability of hypercubes [29]. Thus, the calculated errors are assigned proportional to the inverse of learning times [29]. In [30,31], a CA-CMAC is proposed which uses the inverse of learned times of the addressed hypercubes as the credibility of the learned values. Therefore, it has the advantage of very fast learning and the unique property of quickly training certain areas of memory without affecting the whole memory structure, which is called generalization. There are two basic learning schemes in CMAC: cyclic learning and random learning [32]. Since local generalization is built in conventional CMAC, both of cyclic learning and random learning have a problem named as learning interference or overlearning, which means training of subsequent samples will destroy the precision of previous ones [33]. In addition, random training requires longer periods to achieve a desired performance level than cyclic learning [34]. Since the training speed is very important for real-time system, the cyclic learning is particularly suitable for ISP controller [35]. Therefore, the CA-CMAC algorithm based on cyclic learning algorithm is proposed to reduce learning interference and improve the training speed in conventional CMAC. In [23], a modified weight adjusting rule is proposed to resolve the overlearning issue of CMAC which restrains external disturbance meanwhile.

On the other hand, an important concern to CMAC is the disadvantage in output smoothness. At present, the conventional CMAC control method has been widely used in improving the steady precision and disturbance suppression ability of a nonlinear system. However, the outputs of conventional CMAC are not continuous for consecutive quantized states, which makes the control actions fluctuate [15]. In [36], a modified CMAC-PD control strategy was put forward for a complex nonlinear system to get better dynamic performance. However, although the output errors are significantly decreased by CMAC–PD scheme, the output curves are not smooth which will result in the torque motor vibration and further make the system position control precision decreased [23]. Therefore, smoothing output errors is crucial for CMAC to reduce the torque motor vibration, which can improve the stability and tracking precision of a system through effectively restraining interference of surplus torque and avoiding overlearning of CMAC. There are different disadvantages existing in the former work that require researchers to investigate new methods to improve them. For examples, the learning efficiency and control precision of the conventional CMAC controller are decreased due to the same credits. Although the CA-CMAC algorithm can improve the accuracy and stability of the CMAC control system, the output waveform is normally fluctuated instead of smooth. Therefore, the optimized smoothness (OS) algorithm is crucial for the CMAC to smooth the output errors and further improve the dynamic performance.

In this paper, to improve the dynamic performances of a three-axis aerial ISP, an improved CMAC controller based on the compound algorithms of CA and OS is proposed. By the proposed CA&OS-CMAC compound scheme, the disadvantages such as learning interference and output fluctuation in conventional CMAC algorithm are systematically overcome, eventually leading to higher tracing accuracy and stability. To validate the method, simulations and experiments are carried out separately, in which the LuGre friction model is introduced to represent the effects of main disturbances.

2. Basic background

2.1. Aerial remote sensing system

Fig. 1 shows the schematic diagram of an aerial remote sensing system. The role of the ISP is as a physical and intelligent interface between the imaging sensor and the aircraft to isolate various disturbances, particularly for the attitude changes of aircraft. As shown in the figure, an aerial remote sensing system generally consists of four main components, i.e., an aircraft vehicle, a three-axis ISP, a Position and Orientation System (POS) and an imaging sensor. The POS is used

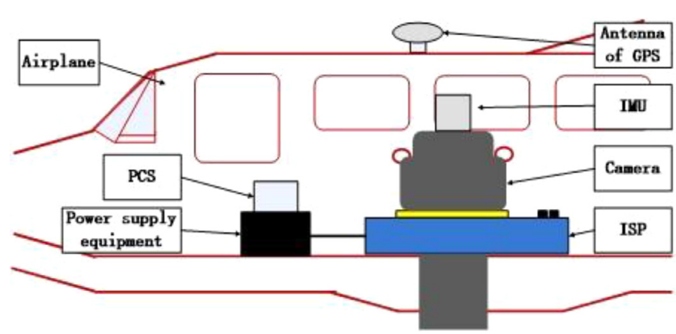

Fig. 1. Schematic diagram of an aerial remote sensing system.