Component-Based Modeling and Simulation of Compound-Axis Tracking Systems

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***Abstract*—Pointing on a certain point of a dynamic target is demanded by beam director system. Compound-axis servo system must be adopted. A component-based compound axis servo system simulation method is proposed, denoted as the CCASS method. Compound-axis tracking system simulation is an effective expansion on EasyLaser, a primary general software platform for laser system simulation. The circumstance nest of Matlab/Simulink makes the CCASS method adaptive to concrete transfer function as well as complex control system. Furthermore, CCAS method aims at searching out a solution for coupling and decoupling simulation of the main-axis and the sub-axis servos, because there are kinematics coupling and driver decoupling problem in a general beam director. Otherwise, a joint simulation with adaptive optical system is derived, which improves tracking precise forwardly. By CCAS method, no matter how the detectors and controlled mirrors are sited in the optical path, kinematical coupling and driver decoupling are resolved automatically. Simulation results indicate that the proposed CCAS method has the capacity of retaining simulative quality and enhancing the simulative facility and adaptability.**

Keywords-simulation; compound axis; servo system; driver decoupling

I. INTRODUCTION

Functional structure of compound-axis can not only improve tracking precise and response speed of photoelectric system, but also keep large dynamic bandwidth range, which is applied widely to target tracking, laser communication, beam stabilization [1]-[5], etc. Moreover, multiple compound-axis structures, including that joint with adaptive optical (AO) system, are important technical routes for new servo systems, in order to achieve higher tracking precise at level of less than micro-radian [1].

Beam director simulation with compound-axis tracking system is important to the system performance estimation and design. The whole simulation program is a complex integration subject to many subjects such as computer, optics, signal process, and control. Advantages based on component simulation are the modularization and incremental reusability of rock-bottom codes. WaveTrain and CAOS are two representative component optical simulation systems [6]-[7]. MATLAB/Simulink is an effective component platform for kinds of transfer function models in control system [8].

Inspired by WaveTrain, we independently propose another primary general software platform for laser system simulation, denoted as EasyLaser, in 2013 [9][10]. As an effective expansion application on EasyLaser, component-based compound axis servo system simulation method, denoted as the CCASS method, is proposed in this paper. Dynamic response of servo is simulated by circumstance nesting scheme, different to WaveTrain. Moreover, CCAS method aims at searching out a solution to realize automatically decoupling simulation of main-axis and sub-axis systems. This problem is not considered in WaveTain because it only emphasizes simulation related to wave optical transmission. We also present a compound-axis servo simulation jointed with an AO system in CCASS method.

II. DESIGN OF EASYLASER

Component-based simulation platform is important for modeling and simulation development. EasyLaser is developed on QT4 circumstance and C++ language, supplying basic running mechanism, editing and running interfaces. Expanded physical devices or physical processes can be abstracted as components in a new founded component library. “Feedback” property is set for a feedback component object. Applying this property, a simulation project with closed loop structure can also be simulated step by step.

III. MODELING OF COMPOUND-AXIS TRACKING SYSTEM

A. Simulation Models Description

Simulation models of compound-axis tracking system are described in Figure 1, which is divided into entitative models and visual models. The former are related to compound-axis system itself except scene model. Sensor imaging model uses scene model to obtain target scene images. Visual models are used to analyze or display different kinds of data. Components are designed to realize simulation models. There are eight basic components designed for the above models:

1) *Scene_source:* It simulates the scattered imaging of target and background.
2) *TV_imaging:* It growes television image.
3) *Imge_Proc:* It processes image and obtaining tracking point.
4) *Predict:* It predicts target position in current step.
5) *Tracking:* It simulates response of a servo system.
6) *Axis_add:* It obtains compound-axis director.
7) *TV_display:* It displays TV images in every step.
8) *State_display:* It works as a oscilloscope.

B. Interface Types of Simulation System

Components describing different physical phenomena or physical process need separate interface definitions. Definition of interface data type is basic for the communications between different components. Only components having same interface data type can be connected by line. Basic interfaces of tracking system in EasyLaser are the three kinds as follows.

1) AXIS_T: It denotes tracking axis direction, target tracking point direction, predicting direction, etc. This interface consists of double data, such as heading angle, pitching angle and rotating angle of a gimbal.

2) TVPLOT_T: It denotes simulative image of TV and TV parameters such as total pixel numbers, resolving powers and view field angles in level or vertical orientations. This interface consists of a 2D double array and some double data.

3) TUOBA_T: It denotes undershoots in level and vertical orientations. This interface consists of double data of undershoots at different units, pixel or degree.

IV. CCASS METHOD

A. Simulink Circumstance Nested as new Component Level

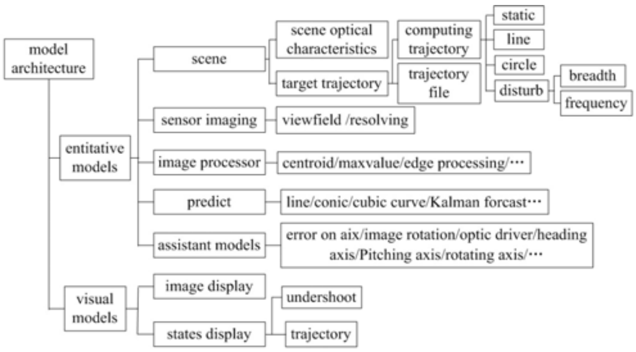

FIGURE I. DESCRIPTIONS OF COMPOUND-AXIS SERVO SIMULATION MODELS

The nested application of Matlab/Simulink belongs to core programs of EasyLaser. Main function is the growing, displaying, parameter setting, changing and saving of Simulink models file, denoted as *.mdl. As we known, control designer often applies Matlab control toolbox and visual simulation circumstance "Simulink" to analyze and design control system. The working flow is kept by circumstance nested mode. First, we select a tracking component from EasyLaser library and pull it into a simulation project. Secondly, we double click the object icon, then a control system file is opened in a new shown Simulink circumstance, as shown in Figure 2. Parameters and connection relationships of blocks can be changed and saved. We note problems as follows.

1) Parameters are set in the Matlab data exchange engine program. The control system file must include a "From Workspace" block and a "To Workspace". For example, in Figure 2, parameters "t", "uu_h" and "cuout_h" are embedded, where "uu_h" means predict heading angle, "cuout_h" means output heading angle of the servo, and "t" is simulation step.

2) In the "Configration Parameters" window embedded in the "Simulation" menu, simulation parameters about "Data Import/Export" are set as follows.

a) Initial state: It is checked and named as "xInitial", for example.

b) Final states: It is checked and named as "xFinal", for example.

c) Dimension: The dimension of the "xInitial" and the row dimension of the "xFinal" are equal and all equal to that of State-Space of this control system.

3) Data exchange: Parameters in Matlab are exchanged with data in EasyLaser at the end of every simulation step "t".

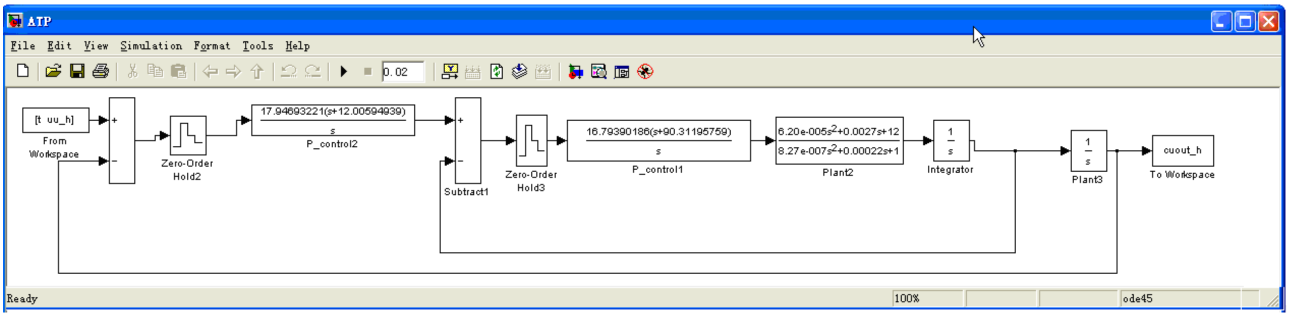

FIGURE II. SIMULINK FILE (*.MDL) USED BY A TRACKING COMPONENT OBJECT

4) Solver: Parameters about "Solver" are related to the core application of Simulink. The solver options decide solver type selected and available simulative tolerance. Generally, ode45 (Dormand-Prince) solver in variable-step type and auto-tolerance setting is suit for most control system.

The whole control system simulation is divided into many segments, and every one means [0, t]. The primary principle is that the whole tracking control process can be divided into many little time segments, only if the initial states of the next latter segment is set by the last states of the former segment. The states in the State-Space are always identical no matter the simulation segment is [t, t+1], [t+1, t+2], ⋯ or [0, t]. In every step, simulation always executes at [0, t]. Disadvantage of the nested mode is that the data exchange mechanism of Matlab restricts simulation in single threading running. However, due to the fact that the Matlab/Simulink itself is well component software, the proposed nested method is meritorious.

B. Auto Solution for Coupling and Decoupling Simulation of Compound Axes

A general beam director system is composed of a gimbal and inner many optical mirrors fixed on respective rotary axis.

If control system simulation and geometry optical transmission simulation are considered simultaneously in a real beam director system, coupling problem is inevitable. Otherwise, the moving devices are gimbal and fast-steering mirrors, drove by undershoot of CCD (Charge Coupled Device) sensors. In order to provide correct control signals, driving uncoupling is necessary.

A compound-axis beam director system with single sensor is founded, as shown in Figure 3. Scattered beam of target scene transfers through atmosphere, telescope, horse shoe mirror, fast-steering mirror (FSM), up 45° mirror, down 45° mirror, etc. At last, it comes into fine television sensor, i.e. FCCD. The image processing object, denoted as "maximum", obtains the undershoot values of tracking point. Predict object achieves current target position by predicting trajectory. Two assistant component objects are used to divide the vector into two double data, one denotes heading angle, the other denotes pitching angle. The main-axis tracking control and sub-axis tracking control systems are applied in succession. The outputs are fed back indirectly to related optical mirrors.

Some special assistant component objects appeared in the project. First, there is an "error on axis" object between the image processing object and the predict object. Secondly, the outputs of main-axis tracking system are transferred to mirrors through "heading axis" or "pitching axis" component objects respectively. Finally, there are an "image rotation" component object and an "optic driver" (named as "FSM driver") component object.

Three devices including telescope, FSM mirror and FCCD are generally sited at respective positions in the geometry optical system, and especially their sites often change for different beam directors. Due to geometry optical transmission effects, their imaging pictures grown from scattered beams will appear geometry rotation conversion. Furthermore, the undershoot values picked from respective images and the driving values applied to FSM should be rotated too. The inputs of "image rotation" component are center ray directions of telescope, FSM mirror, and FCCD. The outputs are three matrixes, which represent three rotate conversions. The process of geometry rotation conversion is called an "optic decoupling" process in the CCASS method.

Nevertheless, we take note of another important conversion in the simulation of compound-axis tracking system. Suppose the heading angle and pitching angle of a gimbal, at time k, are denoted as A_k and E_k respectively. The tracking point deviation from the view axis direction is denoted as $\Delta\alpha$ and $\Delta\beta$. The target tracking point deviation from the center of view field, i.e. undershoot data at level and vertical, is denoted as Δx and Δy. Formula 1 is satisfied [10].

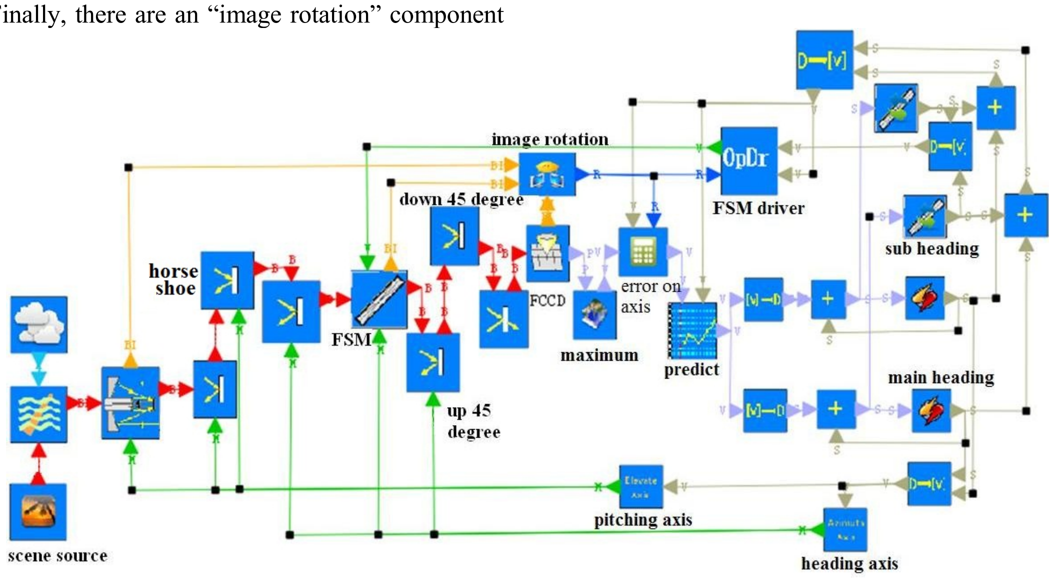

FIGURE III. CUSTOMARY COMPOUND-AXIS SERVO SIMULATION PROJECT

$$\begin{cases} \Delta\beta = \Delta y \\ \cos(\Delta\alpha) = \dfrac{\cos(\Delta x)}{\cos^2(E_k + \Delta y)} - tg^2(E_k + \Delta y) \end{cases} \tag{1}$$

When rotary platform is drove by the undershoot values (Δx, Δy), the conversion according to Formula 1 is needed for the tracking servo system. When the mirrors fixed on the platform is simulated according to the heading angle and pitching angle of rotary platform, the reverse conversion is needed. In the CCASS method, we design the "error on axis" component to realize the former status automatically, and design the "heading axis", "pitching axis" or "rotating axis" component to realize the latter status automatically. Relative to "optical decoupling", process of the two statuses is called "coordinate coupling and decoupling" process in this paper.

C. *Joint Simulation with AO System*

In order to correct optical wavefront and tracking precision, AO system is jointed with a customary beam director system. Applying CCASS method, we discuss the joint system simulation in this section. Mirrors TM (tilt mirror) and DM (deform mirror) are high precise tilt mirror and deform mirror subject AO system. Based on the optical path structure, we can see that the precision stabilizing servo of TM works behind the customary FSM servo, and the two servos form a new level compound-axis system. The control plants of new main-axis and sub-axis tracking systems are FSM and TM respectively. We also note that simulation of this compound-axis system doesn't need the "coordinate coupling and decoupling" process in CCASS method. This is because the two axes are all optic inching systems with no moving gimbal. Multilevel compound-axis tracking system based on the union of gimabal servo system, FSM and AO optical inching servo systems can be modeled and simulated in EasyLaser by using CCASS method.

V. Experiment and Results

Target of joint AO compound-axis system is a static circle expanded target which is disturbed by atmosphere transmission effect. We set the controllers all PI (proportion and integral) type. The tilt item fluctuation of atmosphere is called initial fluctuation, and the level sd. (standard deviation) and vertical sd. are 0.66μrad and 0.84μrad, respectively. The precision stabilizing servo of FSM is designed as: the cutting frequency of open-loop system is 7.8Hz and phase margin is 84°. The servo of TM is designed as: the cutting frequency is 46Hz and phase margin is 62°. According to the error response data, we obtain that the level sd. and vertical sd. of FCCD are 0.28μrad and 0.20μrad, and that of HCCD are 0.18μrad and 0.08μrad. The sub-axis servo of TM advance the tracking performance greatly, based on the main-axis servo of FSM. We choose other two different FSM controllers to compare the effects of diverse servo systems. The lower bandwidth servo is designed as: the cutting frequency is 3.8Hz and phase margin is 80°. The higher bandwidth servo is as: the cutting frequency is 15.9Hz and phase margin is 90°.

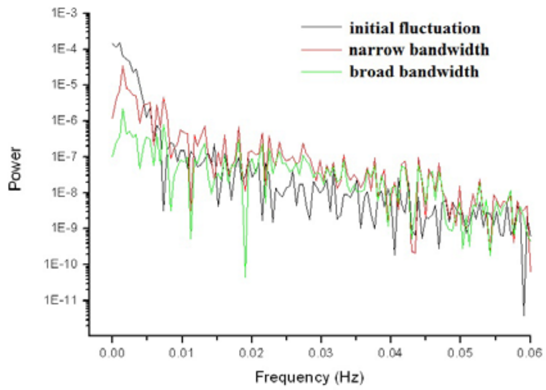

FIGURE IV. DYNAMIC ERROR RESPONSE OF ATMOSPHERE FLUCTUATION

The bandwidth effects of different FSM servo systems with diverse cutting frequencies are compared in Figure 4. Initial fluctuation data and two kinds of servo's restrained error response data in vertical are all analyzed in frequency domain. The broader bandwidth that the servo has, the low frequency elements are more less part in its spectrum, and the breadth of fluctuation is restrained more greatly.

VI. Conclusion

Component-based compound axis servo system simulation method is proposed. In CCASS method, the control system simulation based on nested Matlab/Simulink is involved, and four types of assistant component are designed. Advantage of circumstance nest mode is that the control system designer can do their work expediently and the nesting change is simply, merely the simulation can't be parallel now, unless the data exchange scheme is mended later.

Four types of components proposed in CCASS method consists of "image rotation" component, "optic driver" component, "error on axis" component, and "heading axis", "pitching axis" or "rotating axis" component. Rotary matrixes are numerically updated according to new site and normal direction. The geometry optics and kinematical conversions are embedded in simulation. No matter where the mirror and imaging detector are sited in optical path, all the kinematical coupling and driver decoupling works can be automatically resolved. For multilevel compound-axis system it is also available. We also discuss the compound-axis servo simulation joint with an adaptive optical system. A union simulation experiment for an expanded target tracking is studied. Results show that the CCASS method is meritorious to the algorithm and performance estimations for diverse kinds of beam director systems.

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