Controller Design and Experiment for Tracking Mount of Movable SLR, ARGO-M

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ABSTRACT

Controller design procedure for prototype tracking mount of Movable SLR (Satellite Laser Ranging), ARGO-M is presented. Tracking mount of ARGO-M is altitude-azimuth type and it has two axes of elevation and azimuth to control its position. Controller consists of velocity and acceleration feed-forward controller, position controller at outer loop, velocity controller at inner loop. There are two kinds of position control modes. One is the pointing mode to move from one position to the other position as fast as possible and the other one is tracking mode to follow SLR trajectory as precise as possible. Because the requirement of tracking accuracy is less than 5 arcsec and it is very tight error budget, a sophisticated controller needs to be prepared to meet the accuracy. Especially, ARGO-M is using the cross-roller bearing at each axis to increase the mechanical accuracy, which requires add-on controller DOB (Disturbance observer) to suppress friction load and low frequency disturbances. The pointing and tracking performance of the designed controller is simulated and visualized using MATLAB/ Simulink & SimMechanics and the experimental results using test are presented as well.

Keywords: Satellite Laser Ranging, Tracking Mount, SimMechanics, Tracking accuracy.

1. INSTRUCTION

Currently, Korea Astronomy and Space Science Institute (KASI) is concentrating on a study to develop an altitude-azimuth type movable satellite laser ranging (SLR) and its tracking mount is under development by Korea Institute of Machinery & Materials (KIMM) [1][2][3]. For the development of a robust and precise high-speed tracking mount, the core components including motors, encoders and bearings were selected, and the proto type mount was designed based on them. In this paper, we present the proto type of ARGO-M tracking mount and the procedure of controller design. The verification of the designed proto type mount and controller would be confirmed through the simulation using MATLAB/ Simulink and SimMechanics. With the confidence of the designed tracking mount after simulation, the proto type mount to evaluate the performance by the experiments is constructed.

2. SYSTMEM DESCRIPTION

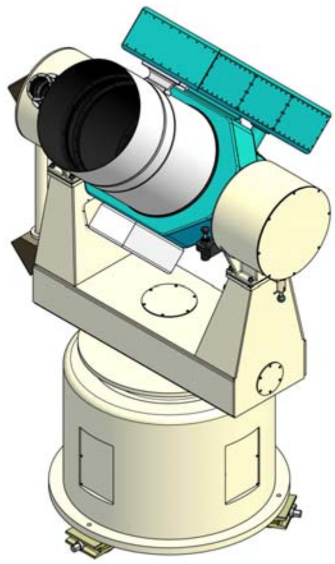

Figure 1. Proto type of ARGO-M tracking mount

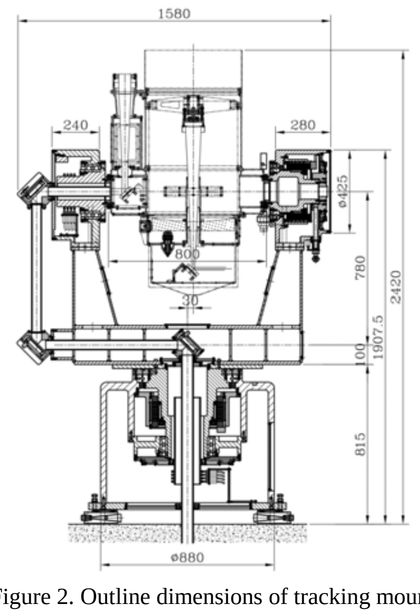

Figure 2. Outline dimensions of tracking mount

The mounts used for astronomical telescopes are classified into altitude-azimuth types and equatorial types. ARGO-M tracking mount adopted altitude-azimuth type which is used in most of SLR systems that have been developed earlier. Figure 1 shows the preliminary design of ARGO-M tracking mount and Figure 2 shows the dimension of the designed tracking mount. The main parts that consist of tracking mount are the mount base and frame, optical interface and axis-driving parts. Tracking mount supports the reception optical system of 40 mm-caliber and transmission optical system of 10 mm-caliber. In order to avoid the damage to the optical system due to the abrupt motion, driving speeds for azimuth and elevation axes are limited to 20 deg/sec and 10 deg/sec, respectively. Driving range for azimuth axis is ±350 deg which is almost two revolutions from one side rotational limit to the other one, and driving range for elevation axis is 0–180 deg which is a half revolution from one horizontal limit to the other one. ARGO-M will track satellites which are located in the altitude of 300-25,000 km and the pointing accuracy should be less than 5 arcsec, or 5 over 3,600 deg. Table 1 describe the specifications of ARGO-M tracking mount. Core components such as motors, encoders and bearing were selected to meet the operating specifications. The continuous torque of motors for AZ and EL axes are 344 N·m and 138 N·m , respectively, and the encoder resolution for AZ and EL axes are 0.020 arcsec and 0.032 arcsec, respectively. The cross roller bearing with the precission class of P2 was selected for both axis.

Table 1 Specifications of ARGO-M tracking mount

Item	Specifications
Mount type	Alt-Azimuth (EL over AZ)
Telescope caliber	Separable transmission-reception type (10 cm, 40cm)
Mount driving speed	Azimuth: Max 20 deg/sec Elevation: Max 10 deg/sec
Mount driving acceleration	Azimuth: 5deg/sec2 or higher Elevation: 2deg/sec2 or higher
Mount driving range	Azimuth : ±350deg Elevation: 0-180deg
Satellite altitude range	300 – 25,000 km
Mount pointing accuracy	Less than 5 arcsec

3. CONTROLLER DESIGN

Before fabricating the mount, it was necessary to predict the tracking and pointing accuracy of ARGO-M tracking mount based on the designed proto type mount. The simulation was performed by using MATLAB/ Simulink shown as Figure 2. Generally, plant model for the dynamic simulation is constructed from the derivation of the equation of motion. Because the moment of inertia along the azimuth axis changes depending on the position of the system along the elevation axis, the tracking mount is a nonlinear system; a simple 1 DOF (degree of freedom) modeling is not sufficient for precise simulation. In this study, the plant model was constructed by using Simulink/ SimMechanics [4]. By using SimMechanics, three- dimensional CAD model which is constructed using software such as Solidworks can be converted to a multi-body dynamic model, and it can be included in MATLAB/Simulink model and the control simulation can be easily conducted. Figure 3 is the SimMechanics block diagram of ARGO-M tracking mount which has 2 mass bodies and 2revolute joints.

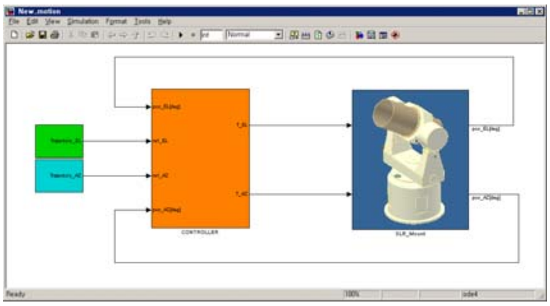

Figure 2. Simulink block diagram to simulate the control performance of ARGO-M tracking mount

The controller was designed for both of pointing motion and tracking motion. For the pointing motion, the controller tries to rotate the mount from one location to another as quickly as possible without residual vibration. There is a trajectory generator to produce the position, velocity and acceleration trajectory for the purpose of feed-forward. The structure of controller is a dual loop, which is same for each AZ and EL axis. The dual loop consists of an inner velocity controller and outer position controller and the control method is the proportional-integral (PI) control and disturbance observer (DOB) to suppress the friction disturbances of bearings. Figure 4 shows the controller block diagram for both of AZ and EL axis. After selecting PI gains for each velocity and position controller of each axis, they are optimized by using Simulink/Optimization toolbox.

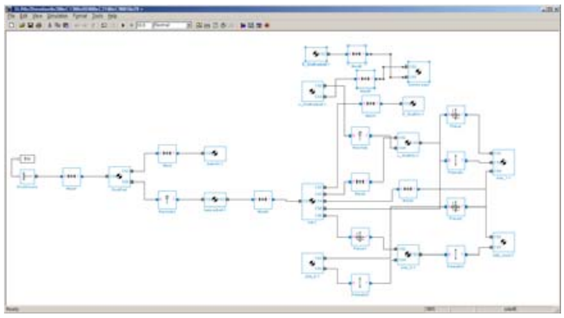

Figure 3. SimMechanics block diagram of ARGO-M tracking mount

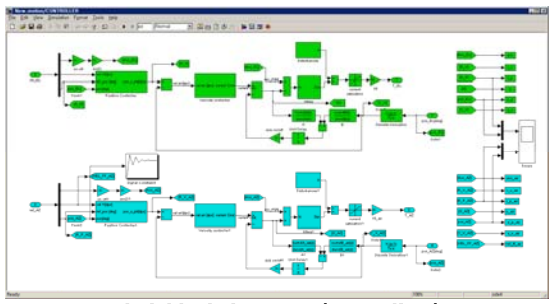

Figure 4. Simulink block diagram of controller for ARGO-M tracking mount

4. SIMULATION RESULTS

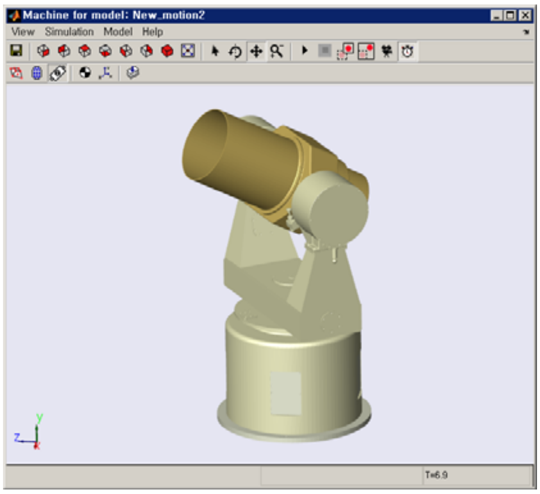

Figure 5. Animation in SimMechaincs to show the motion of ARGO-M tracking mount

The one of merits which can be obtained using SimMechanics is that it is easy to visualize the motion of tracking mount during simulation shown as Figure 5. It can help the designer improve the feeling of plant motion, select the right operating directions and make it easy to explain the simulation results to the other persons.

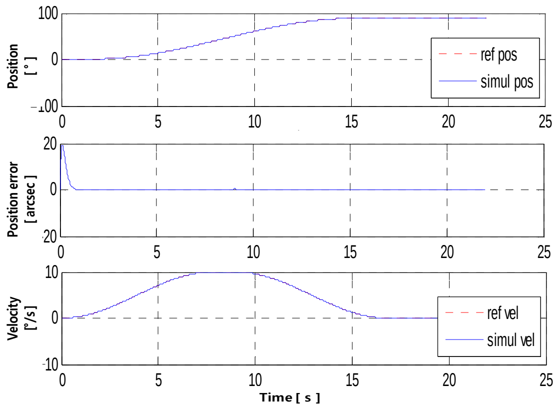

Figure 6. Simulation results of EL axis pointing motion

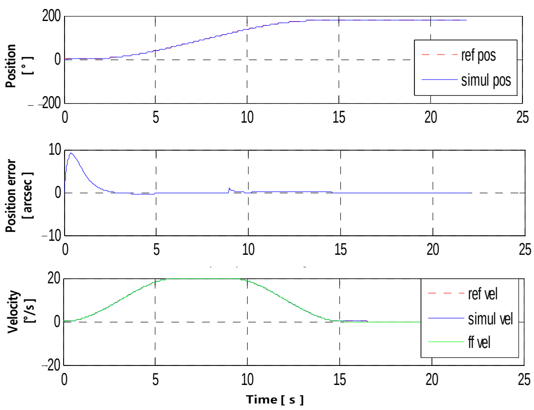

Figure 7. Simulation results of AZ axis pointing motion

Firstly, pointing motion simulation for the tracking mount was performed. Pointing reference position was given from 0 to 90 deg for elevation axis, and from 0 to 180 deg to azimuth axis. The simulation results are shown in figure 6 and 7. During pointing operation, max velocities for EL and AZ axes are limited to 10 and 20 deg/sec, respectively, as described in the specifications of Table 1. Reference position angles from starting point to end point are given with the integral of velocity trajectories. The position errors are converged less than 0.1arcsec within 3sec and the controller keeps the small position errors under the pointing error specification of 5 arcsec with enough margins for both axes.

Secondly, tracking motion simulation for the tracking mount was performed using the trajectories of International Space Station (ISS). The average altitude of the ISS is 373.7 km, and it is the representative of the satellites at the lowest altitude in comparison with the altitude specification of the satellites to be tracked by the ARGO-M (300 – 25,000 km). Therefore, the trajectories of this satellite can be the representative for all the required speed ranges along each axis to track satellites from the lowest speed to the highest speed. Velocity feedforwards for each axis were injected using the derivative of the position trajectories of ISS. The maximum velocities for EL and AZ axes during tracking simulation are 1 and 8.5 deg/sec, respectively. It was predicted that the position errors are less than 1 arcsec for the whole tracking motion with sufficient margins for both axes.

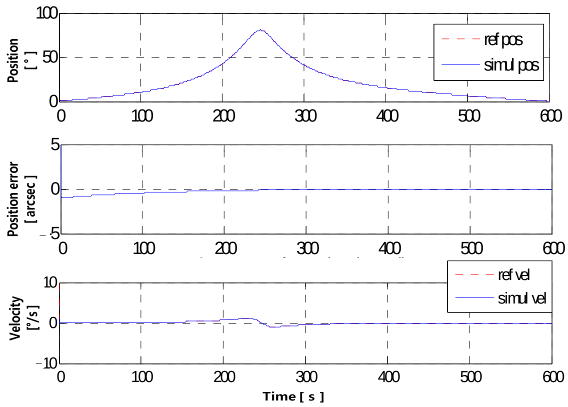

Figure 8. Simulation results of EL axis tracking motion

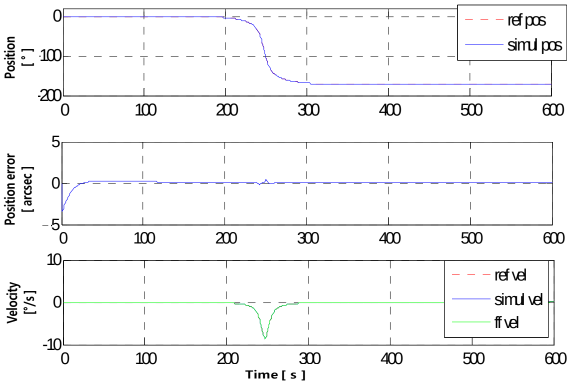

Figure 9. Simulation results of AZ axis tracking motion

4. EXPERIMENT

The prototype of ARGO-M tracking mount was manufactured shown in Figure 10. The system accuracy was evaluated by measuring the mechanical repeatability along each axis. The values of repeatability were 0.89 arcsec and 0.54 arcsec for AZ and EL axis, respectively. In order to evaluate the tracking performance, the tracking experiment was performed by using the trajectories of ISS which has been used in the simulation. Figure 11 and 12 shows the tracking performance for each axis. It was found that the position errors are less than 1 arcsec for the whole tracking motion in both axes as the simulation has predicted.

Figure 10. Manufactured prototype of ARGO-M tracking mount

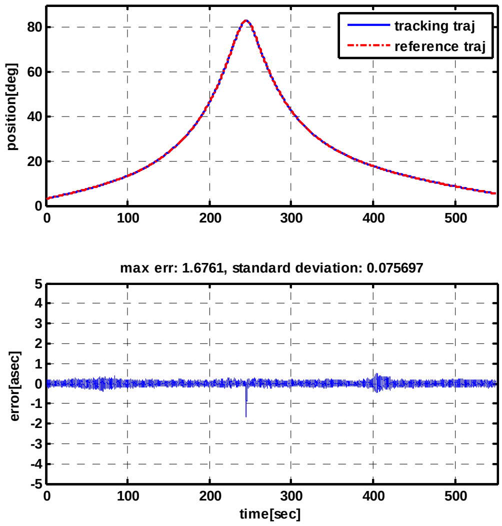

Figure 11. Experimental results of EL axis tracking motion

5. CONCLUSION

In this study, we have presented the controller design procedure and experimental results for the proto type design of ARGO-M tracking mount. Plant model for tracking mount is constructed using MATLAB/SimMechanics, and the motion simulation is performed using MATLAB/ Simulink. From the simulation results, it was predicted that both of pointing and tracking motion could meet the accuracy specification with sufficient margin. However, this simulation has a limitation that it can reflect the rigid body motion only although there is a couple of flexible modes in the real tracking mount. The proto type mount was constructed and the experiments to evaluate its repeatability and tracking performance were performed. It was found that the experimental results were satisfactory to meet the performance specification of the tracking mount. In the future, the final tracking mount will be constructed base on the results of this study.

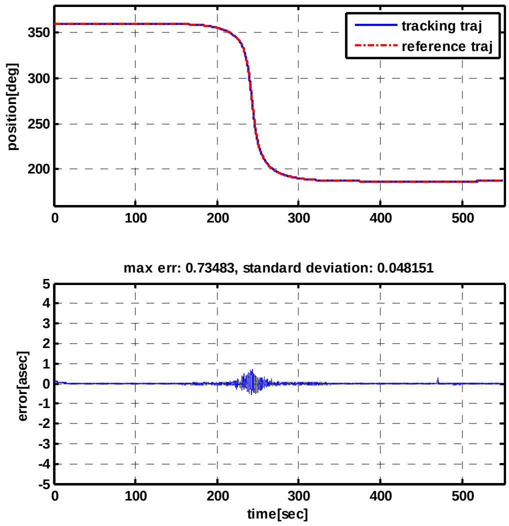

Figure 12. Experimental results of AZ axis tracking motion

6. REFERENCES

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