Digital twin technology improves the visualization of telescope drive system

Yun Li, Shihai Yang, Xiaojie Gu, Zhuangzhuang Deng, Yu Ye, et al.

Yun Li, Shihai Yang, Xiaojie Gu, Zhuangzhuang Deng, Yu Ye, Jin Xu, Bozhong Gu, "Digital twin technology improves the visualization of telescope drive system," Proc. SPIE 12187, Modeling, Systems Engineering, and Project Management for Astronomy X, 121871U (25 August 2022); doi: 10.1117/12.2637180

Event: SPIE Astronomical Telescopes + Instrumentation, 2022, Montréal, Québec, Canada

Digital Twin Technology Improves the Visualization of Telescope Drive System

Yun Li[a,b], Shihai Yang[*a,b], Xiaojie Gu[a,b,c], Zhuangzhuang Deng[a,b,c], Yu Ye[a,b], Jin Xu[a,b], Bozhong Gu[a,b]
[a]National Astronomical Observatories/Nanjing Institute of Astronomical Optics & Technology, Chinese Academy of Science, 188Bancang Street, Nanjing 210042, P. R. China;
[b]CAS Key Laboratory of Astronomical Optics & Technology, Nanjing Institute of Astronomical Optics & Technology, Nanjing 210042, P. R. China;
[c]University of Chinese Academy of Science, Beijing 101400, P. R. China;

ABSTRACT

Aiming at the lack of effective visualization strategies for the operation and maintenance of the telescope drive system, this paper proposes to use digital twin technology to improve telescope driving system visualization. Firstly, visual modeling techniques are used to construct the digital twin model of the telescope drive system. Then, the mapping relationship between the physical and digital twin of the telescope drive system is established, and the real-time mapping of the digital twin operation status is realized through the physical parameters, historical operation data and sensor data of the drive system. Finally, the intelligent operation and maintenance strategy of the telescope is formulated using the digital twin of the drive system visualization. This research will solve the visualization problems in the telescope drive system, and has practical significance for improving the operation efficiency of the telescope and formulating efficient maintenance strategies.

Keywords: Telescope, drive system, digital twin, visualization, maintenance strategies

1. INTRODUCTION

The telescope is an essential scientific equipment for astronomy and celestial physics research, and the drive system is the power source of telescope operation, and it is also the key to ensuring smoothness of astronomical observations. Most telescopes are built in areas where the natural environment is harsh, such as the highlands, polar regions or space, with few people, little light pollution and good eyesight. Due to its unique geographical location and natural environment, Demo A in the Antarctic has become the astronomical observatory site with the best visibility found on earth[1], with observation conditions comparable to those in space. In addition, The Cold Lake Astronomical observation Base in China[2] and Mauna Kea Mountain in Hawaii[3] are all relatively ideal astronomical observation sites on Earth.

At present, most telescopes perform astronomical observations through remote control, especially for unattended telescope, can only pass this way, such as China Antarctic patrol telescope AST3[4].

Figure 1. Antarctic Survey Telescope in Dome A

For remotely controlled telescopes, the visualization technology of drive system helps observer to monitor and master

---

*shyang@niaot.ac.cn; phone: +86 025-85482241

Modeling, Systems Engineering, and Project Management for Astronomy X, edited by
George Z. Angeli, Philippe Dierickx, Proc. of SPIE Vol. 12187, 121871U

doi: 10.1117/12.2637180

its status in real time. Such as Antarctic Telescope, Space Telescope and other telescopes of the same type. The drive system is the power source of the telescope, and it is the key to ensure the success of astronomical observations. The visualization research of the telescope drive system is of great significance to describe the operating status and improve the maintenance efficiency, and it will also help the intelligent operation of telescope.

Digital twin[5] is one of the ten most promising emerging technologies in the future, as well as one of the core technologies in the development of the Metaverse. It was born due to the demand for digital maintenance of military equipment. Digital twin is a simulation process that makes full use of physical models, sensor updates, historical operation data, and integrates multi-disciplinary, multi-physics, multi-scale, and multi-probability simulation processes to complete mapping in virtual space, thereby reflecting the periodic operation process of the telescope drive system.

Digital Twin was first proposed by the US Air Force Research Laboratory in 2011. It was initially used for the digital maintenance of fighter jets. Subsequently, General Electric and Siemens also regarded it as one of the ten most promising technologies in the future. Around 2015, domestic research institutions and enterprises also invested in research topics related to Digital Twins, mainly in the fields of industrial manufacturing, smart cities and health management. The research hotspots of digital twin technology in the field of health management focus on predictive maintenance, condition monitoring, fault detection and diagnosis, and performance prediction[5].

Digital twins have achieved important research results in the fields of fault diagnosis and health monitoring of satellite power systems[6], aero-engine bearing maintenance strategies[7], and health monitoring and prediction of automotive synchronous motor drives[8]. At the same time, digital twins are also of great significance to boosting Industry 4.0[9-10].

Digital twin has gained some achievements in telescope maintenance. Researchers from the National Astronomical Observatories of the Chinese Academy of Sciences (CAS) have established a prediction and health management system for the cable network structure of the Five-hundred-meter Aperture Spherical radio Telescope (FAST) using the digital twin technology. The system can effectively guarantee the healthy and safe operation of the cable network structure, greatly improve the maintenance efficiency and reduce the maintenance cost[11]. By analyzing the structure of the active reflection surface of FAST, the digital twin model of the reflection unit of FAST is established, which provides a reference for the application of digital twin technology in the maintenance of large scientific research facilities[12]. Tomasz Bednarz et al. developed a digital twin model extension framework for visual monitoring of the Australian Square Kilometre Array Pathfinder (ASKAP) radio telescope[13]. Beijing space vehicle overall design researchers design hard X-ray modulation telescope (HXMT) flying off satellite digital system, the system can be the "mirror image" of the satellite on-orbit state, in the digital state interpretation of twin on the body to carry out the satellite, control parameter optimization, the design of satellite mission iterative simulation and so on, completed the satellite mission planning and performance improvement[14]. The application of digital twinning in a telescope is shown in Fig.2.

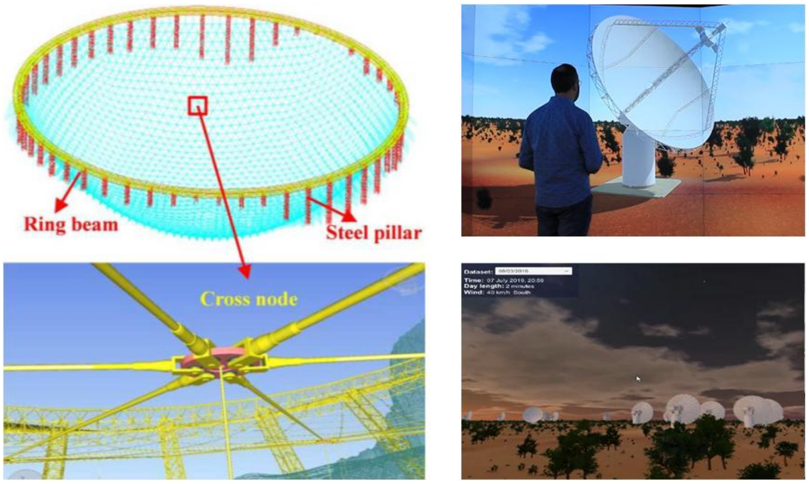

Figure 2. FAST and ASKAP Telescope digital twin model

The rest of this paper is organized as follows: Section 2 presents the notion of telescope drive system. It also shows digital twin frameworks and platform about telescope drive system. Section 3 provides the model building and updating about telescope drive system. It also describes the meaning of visualization. Section 4 summarizes the whole paper and point out the application forward in the future.

2. ESTABLISHMENT OF THE DIGITAL TWIN MODEL FOR TELESCOPE

2.1 Notion of Telescope drive system

The drive system is the power source for the operation of the telescope, and is the key to ensuring the smooth progress of astronomical observations. The large-aperture telescope drive system mostly adopts the direct drive of the torque motor combined with the three-ring servo control method to realize the pointing and tracking during astronomical observation. The realization of the current closed-loop is completed by the driver, which also plays the role of overcurrent protection while completing the current closed-loop control. The realization of speed closed-loop and position closed-loop is usually done by the photoelectric encoder to accurately measure its angular displacement and convert it into position and speed information, which is finally completed by the controller. The speed closed loop can also be realized by installing a resolver. The working principle of the telescope drive system is shown in Fig.3.

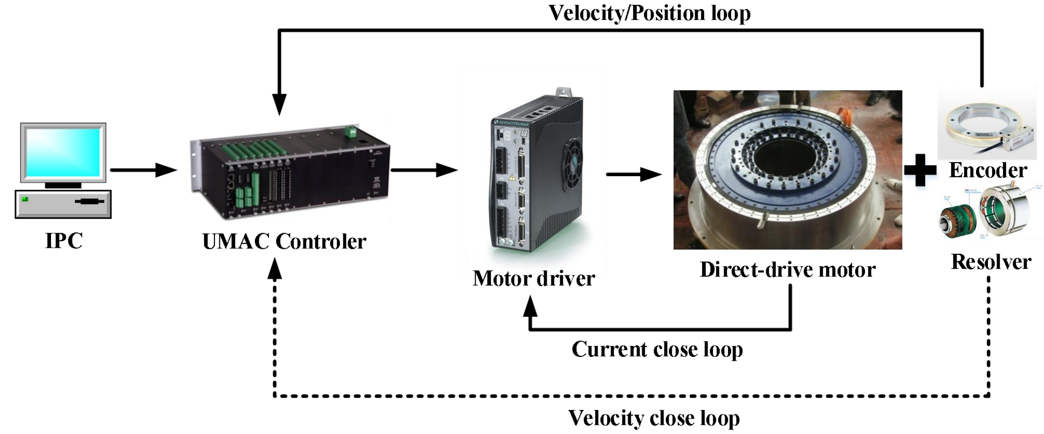

Figure 3. State description of the telescope drive system

The controlled objects of the telescope drive system include azimuth/right ascension axis, elevation/declination axis, focusing subsystem, M2/M3 adjustment subsystem, derotation subsystem and filter switching subsystem. In this paper, the visualization of active optics and adaptive optics system will be added on the basis of the application achievements. The above research objects are all key motion control components of the telescope, and the attitude adjustment of them is directly related to the overall performance of the telescope and the quality of astronomical observations. The distribution diagram of the research objects in this paper is shown in Fig.4.

2.2 Visualization framework based on digital twin

The visualization framework of the digital twin-based telescope driving system shown in Figure 5 is divided into two parts: the virtual telescope body and the physical telescope body. The virtual body works in the client and the physical body works in the observatory, and the former is the corresponding digital twin of the latter.

The physical body of the telescope driving system is established based on the physical model, which consists of physical parameters, design indexes, driving subsystem and other subsystems. Meanwhile, it is equipped with a self-sensing system for data collection and analysis. The virtual body of the telescope driving system is established on the digital twin model, which consists of state description, behavioral decision, fault diagnosis and intelligent prediction and other functions. Meanwhile, it is realized based on data-driven model strategy.

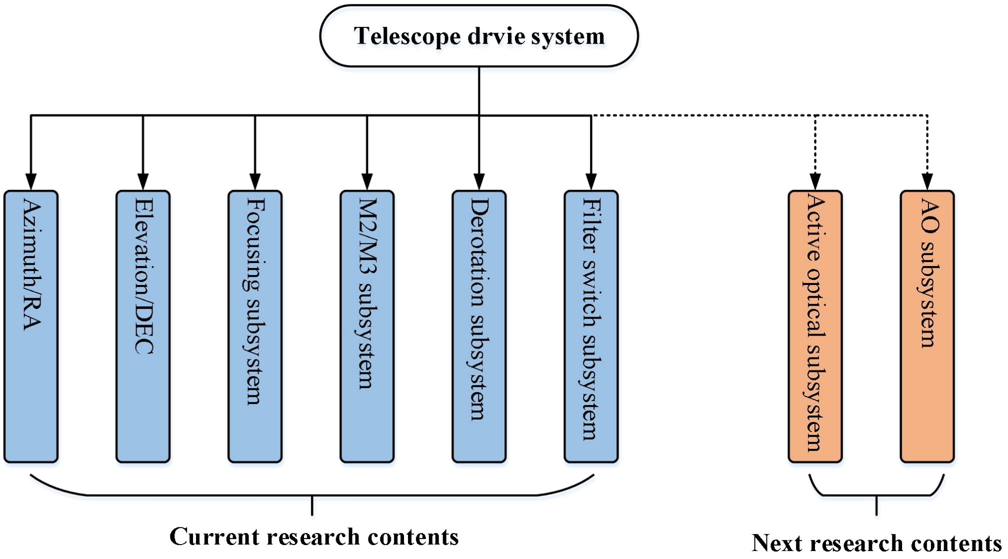

Figure 4. Research object of this paper

The real-time operating data of the telescope drive system is the bridge connecting the physical body and the virtual body. The visualization of the telescope drive system helps to realize its intelligent operation including intelligent maintenance, intelligent prediction, and intelligent decision-making, which is of great significance.

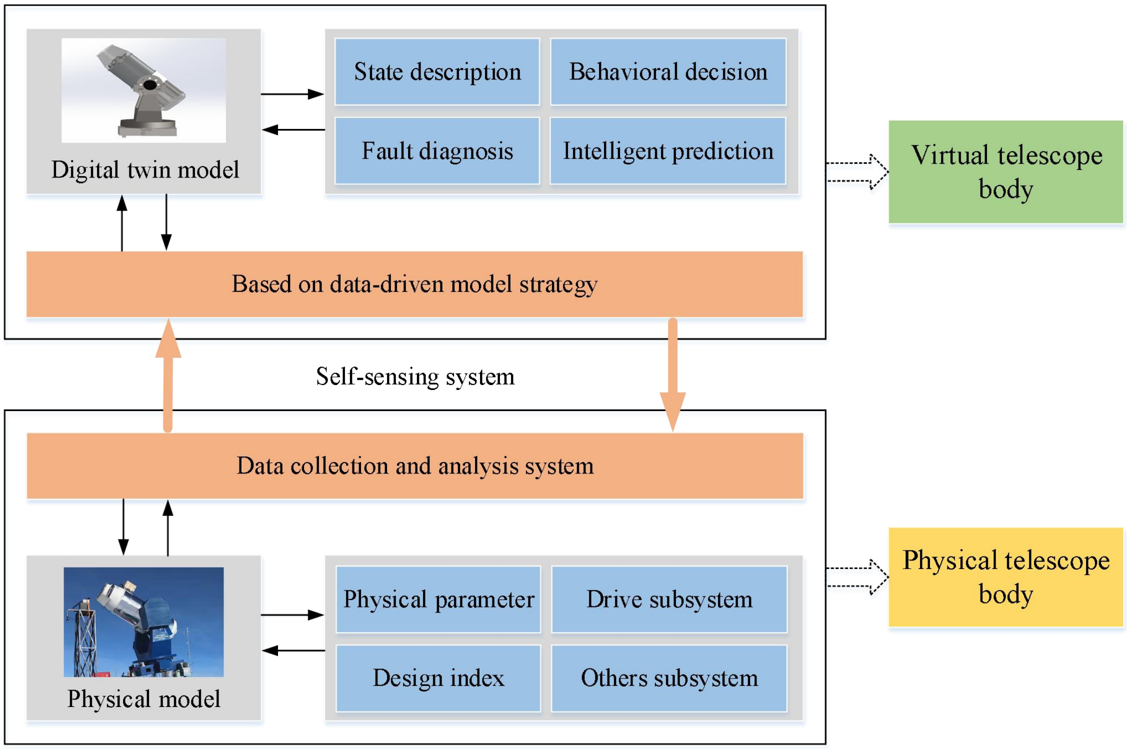

Figure 5. The visualization framework of the digital twin-based telescope driving system

2.3 Digital twin platform for drive system

The digital twin platform combines the physical world and the virtual world, it is constructs the digital space through digital twin technology, and accurately describes the digital space. On this basis, we can diagnose, predict and make decisions on the physical space through the description of the digital space, and then assist the telescope to operate and manage more intelligently.

The digital twin platform of the telescope drive system should have three characteristics: digitization, real-time and intelligence.

1. Digitization.

Digitization is a necessary condition for the digital twin platform, which is to digitize the static or dynamic physical world, so that the physical world and the digital world have better mapping and correlation.

2. Real-time.

Real-time is an important link for mapping and correlating the physical world to the digital world. Low-latency and high-bandwidth data transmission can ensure real-time feedback of the telescope's operating status.

3. Intelligence.

Intelligent diagnosis, prediction and decision-making are the ultimate goals of digital twin platforms. A dynamic and real-time digital mapping body can provide more intelligent operation and maintenance strategies for telescopes in physical world.

3. VISUALIZATION STRATEGIES FOR TELESCOPE DRIVE SYSTEM

Establishing the self-sensing capability of the telescope drive system is the primary task of realizing the visualization strategy, and then using real-time data and digital twin models to achieve data-driven model updates. Finally, the intelligent operation of the telescope is realized under the real-time digital twin model, such as fault diagnosis, unanticipated state research, intelligent prediction.

3.1 Construction of self-sensing system

The construction of the self-perception capability of the telescope drive system is the foundation of this research, and it is inseparable from the construction of the sensor network. Position encoders, angular motion monitors, length gauges, voltage and current sensors, etc. are essential signal acquisition devices for self-sensing systems. The absolute position encoder is installed coaxially with the motor, which can actively provide the precise position information of the main shaft of the telescope to the outside world, and the speed, acceleration, following error, error RMS, etc. can be further obtained through the controller calculation. The angular motion monitor can directly provide information such as position, angle, velocity, angular velocity, acceleration, angular acceleration, quaternion, etc. It can be installed on the outside of the telescope barrel and at the axial position parallel to the azimuth axis. The length gauge can provide the precise position information of the focusing platform to the outside, and at the same time adjust the terminal instrument to the accurate focus position with the stepper motor. Current and voltage sensors are necessary for monitoring the drive system, which can reflect various unexpected states such as abnormal changes in the telescope drive system load, motor failure, and environmental changes. In addition, the signal acquisition and data processing system is also an important part of the self-perception capability construction scheme of the drive system.

The construction principle of the telescope drive control self-perception system is shown in Fig.6.

3.2 Visual modeling and updating

The visual modeling of the key moving parts and controlled objects of the telescope drive control system, as well as the data-driven real-time model updating mechanism are the important parts of the research content of this paper.

The operation of the telescope is realized by remote control. For example, the Antarctic Telescope, which works in extreme environment and is unattended, can only obtain the position information of the attitude through digital deduction, lacking intuitive and efficient visualization strategy. Observing on-site surveillance video equipment can provide rough attitude information, but it is prone to the risk of signal interruption in extreme environments. In this paper, the construction of the self-sensing system of the field control system for the operation of the telescope is studied, and then the key moving parts and controlled objects are visualized with the visual modeling technology. Meanwhile, the attitude of the telescope is displayed in the remote visual terminal of the telescope in real time combined with the self-sensing data provided by the sensor system. This research will greatly improve the visualization form of the telescope control terminal and greatly improve the operation strategy of the staff.

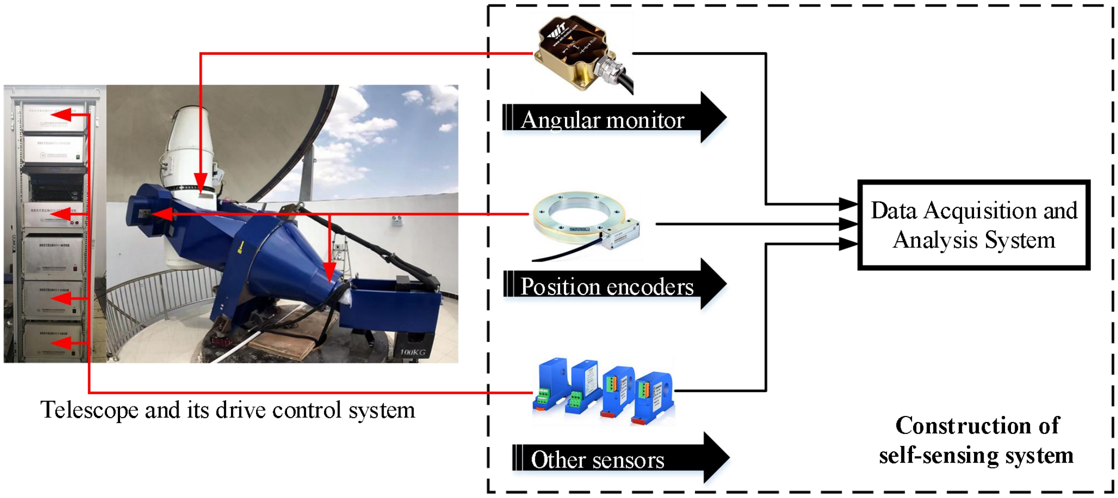

Figure 6 Construction principle of the telescope drive control self-perception system

The visualization strategy based on attitude self-sensing is shown in Figure 7.

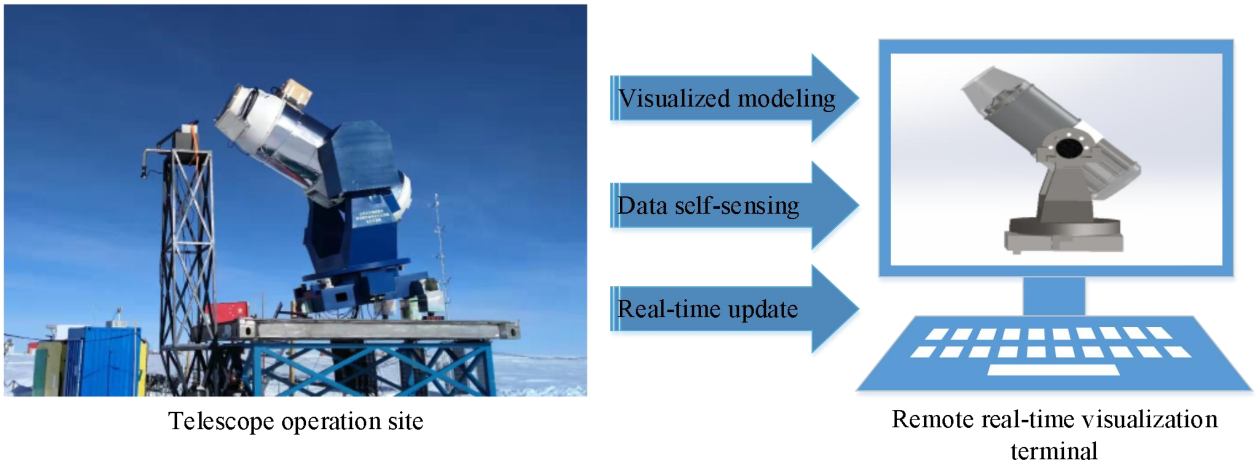

Figure 7 Visualization strategy based on attitude self-sensing

3.3 Significance of Visualization of Telescope drive system

The self-sensing and visualization of the telescope drive system are the basis for formulating intelligent operation strategies. The remote real-time visualization terminal displays the operation status information of the telescope and marks the suspected abnormal status information. The telescope intelligent operation strategy realized by self-sensing and visualization mainly includes state description, fault diagnosis, behavior decision and intelligent prediction.

Status description refers to displaying the operating status of the telescope in a more intuitive digital form on the visual terminal, providing users with more convenient remote operation guidance. At the same time, it can also provide fault diagnosis services to help efficient fault detection and positioning, and achieve a certain degree of fault self-healing function with the help of software, thereby improving the behavioral decision-making ability of the telescope itself. In addition, the intelligent operation decision-making system can also provide intelligent prediction functions of the unanticipated state, operating temperature, Mean Time Between Failures(MTBF) and son of the driving system.

The intelligent operation strategy of the telescope drive system is shown in Figure 8.

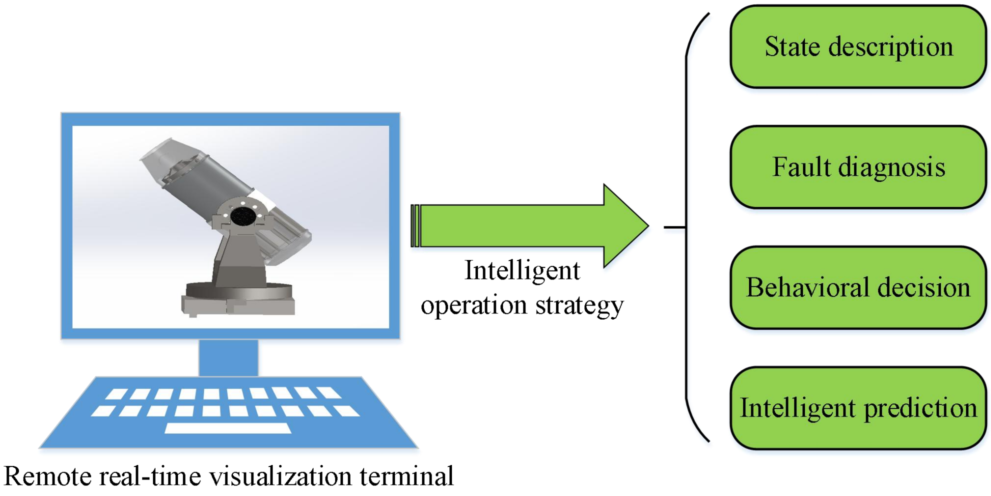

Figure 8. Intelligent operation strategy of the telescope drive system

4. CONCLUSION

Starting from the actual problem of the lack of visualization and intelligent operation strategies of the current telescope drive system, a visual digital twin platform of the telescope drive system is constructed by combining the digital twin technology. This research is helpful to realize intelligent diagnosis, prediction and decision of telescope operation, and is of great significance to telescope operation management.

ACKNOWLEDGEMENTS

The authors are grateful for the support by the National Natural Science Foundation of China (Grant No. 11973065, U1931207, 11373052) and Jiangsu Funding Program for Excellent Postdoctoral Talent to this paper. The authors gratefully acknowledge the support of the National Astronomical Observatories / Nanjing Institute of Astronomical Optics & Technology, Chinese Academy of Science.

REFERENCES

[1] Ma B, Shang Z, Hu Y, et al. Night-time measurements of astronomical seeing at Dome A in Antarctica[J]. Nature, 2020, 583(7818): 771-774.
[2] Deng L, Yang F, Chen X, et al. Lenghu on the Tibetan Plateau as an astronomical observing site[J]. Nature, 2021, 596(7872): 353-356.
[3] Roddier F J, Cowie L L, Graves J E, et al. Seeing at Mauna Kea: a joint UH-UN-NOAO-CFHT study[C]. Advanced Technology Optical Telescopes IV. International Society for Optics and Photonics, 1990, 1236: 485-491.
[4] Cui X, Yuan X, Gong X. Antarctic schmidt telescopes (ast3) for dome a[C]. Ground-based and Airborne Telescopes II. SPIE, 2008, 7012: 952-959.
[5] Yang D, Karimi H R, Kaynak O, et al. Developments of digital twin technologies in industrial, smart city and healthcare sectors: a survey[J]. Complex Engineering Systems, 2021, 1(1): 3.
[6] Shangguan D, Chen L, Ding J. A digital twin-based approach for the fault diagnosis and health monitoring of a complex satellite system[J]. Symmetry, 2020, 12(8): 1307.
[7] Liu Z, Chen W, Zhang C, et al. Data super-network fault prediction model and maintenance strategy for mechanical product based on digital twin[J]. IEEE Access, 2019, 7: 177284-177296.
[8] Venkatesan S, Manickavasagam K, Tengenkai N, et al. Health monitoring and prognosis of electric vehicle motor using intelligent-digital twin[J]. IET Electric Power Applications, 2019, 13(9): 1328-1335.
[9] Xu Y, Sun Y, Liu X, et al. A digital-twin-assisted fault diagnosis using deep transfer learning[J]. IEEE Access, 2019, 7: 19990-19999.

[10] Deebak B D, Al‐Turjman F. Digital twin assisted: Fault diagnosis using deep transfer learning for machining tool condition[J]. International Journal of Intelligent Systems, 2021, 1-28.

[11] Li Q W, Jiang P, Li H. Prognostics and health management of FAST cable-net structure based on digital twin technology[J]. Research in Astronomy and Astrophysics, 2020, 20(5): 067.

[12] Zhang T, Guo Y, Zhang Q H, et al. Creation of Digital Twin Model for FAST Reflector Elements [J].Modern Computer, 2020(25): 15-21.

[13] Bednarz T, Branchaud D, Wang F, et al. Digital Twin of the Australian Square Kilometre Array (ASKAP)[C]. SA 20: SIGGRAPH Asia 2020. 2020.

[14] Miao Y M, Zhao C, Gu Q Y, et al. Design and Application for HXMT Digital Companion Satellite System [J]. Spacecraft Engineering, 2018, 27(5): 46-49.