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The research of intelligentization of control systems for large astronomical optical telescopes

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ABSTRACT

Due to the high complexity of the system and the variety of influencing factors of large astronomical telescopes, the current control system could be improved largely. It’s difficult for traditional automatic control technologies to ensure reliable and highly efficient operation. The key problem is such a system which needs to consider not only the various internal factors but also the various external factors. In addition, some factors are difficult to be digitized. Thus, it’s hard to make mathematical models to represent such complex and dynamic systems. The first goal of this project is to construct a software experimental platform for the intelligentization. The second goal is to develop an intelligent reliability management system, and an optimization system for observation quality. These application systems will be running using the historical data of LAMOST operation. The evaluation of such systems will be based on the simulation of these data.

Keywords: Telescope Control System, Reliability management, Optimization of observation quality, Artificial Intelligence Applications，Intelligent decision support

1. INTRODUCTION

Under the development of science and technology, the locations of telescopes will be at more and more extreme places. This is a huge challenge to the operation and management of telescopes. It's difficult for traditional automatic control technologies to ensure reliable and highly efficient operation. The key problem is that such a system needs to consider not only the various internal factors but also the various external factors. In addition, some factors are difficult to be digitized. Thus, it's hard to make mathematical modals to represent such complex and dynamic systems.

Based on our working experiences in the LAMOST telescope operation and management, there are urgent requirements for the improvements of reliability management, and observation quality. The LAMOST is the world’s most powerful meter-class level ground astronomical optical survey telescope. It has produced more than 10 million spectrum. There are two aspects which can be improved for the telescope control system.

First is reliability management. The LAMOST control system is a large and complex system. The telescope consists of tens of thousands of instruments. Some instruments have been working for more than 10 years, so malfunction is inevitable. If some instruments go wrong, it will influence observation. Sometimes we had to stop observing to eliminate the trouble. Reliability management is one of the methods to increase the efficiency of observation and decrease the cost of operation of the telescope.

Second is Observation quality optimization. The image quality of an optical telescope is limited by site seeing, dome seeing and mirror seeing. The temperature difference between the inside and the outside of the dome and temperature gradient around the structure causes dome seeing and thermal distortions in the telescope structure. The outside temperature always decreases faster than the inside temperature during the observation. To ensure good dome seeing, a cooling system should be used.

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Many attempts have been made to reduce the dome seeing and mirror seeing during the design, construction and commissioning process.

The first goal of this project is to build a software experimental platform for the intelligentization of operation and management based on the new generation AI technology. The integration of knowledge graph, deep learning and intelligent agents will be used. The second goal is to develop an intelligent reliability management system, and an optimization system for observation quality based on the software platform. These application systems will be run using the historical data of LAMOST operation. The evaluation of such systems will be based on the simulation of these data. The research outputs of this project can provide advanced guidance for the intelligentization and development of current and next generation telescopes of China.

2. SOFTWARE EXPERIMENTAL PLATFORM

The large Astronomical optical telescope control system consists of multiple subsystems, which need to run multiple services at the same time. If a set of specialized software is developed for each service, the development cost will be too high. It will be difficult to collaborate organically between software services. Inspired by the idea of software-as-a-Service, this project intends to use meta-Service technology to build an experimental platform for technical support for the control application system of large astronomical optical telescopes. The platform will include a variety of basic functions. The platform can be built into a number of meta-services which will be provided to application developers based on these functions. By integrating and redeveloping the base element services, developers have the flexibility to customize intelligent software for control systems for different telescopes, which can significantly reduce development time and maintenance costs. The overall framework design of the experimental platform is shown in Figure 1, which contains four levels and the developer's functional interface. Each part of the framework is described as follows:

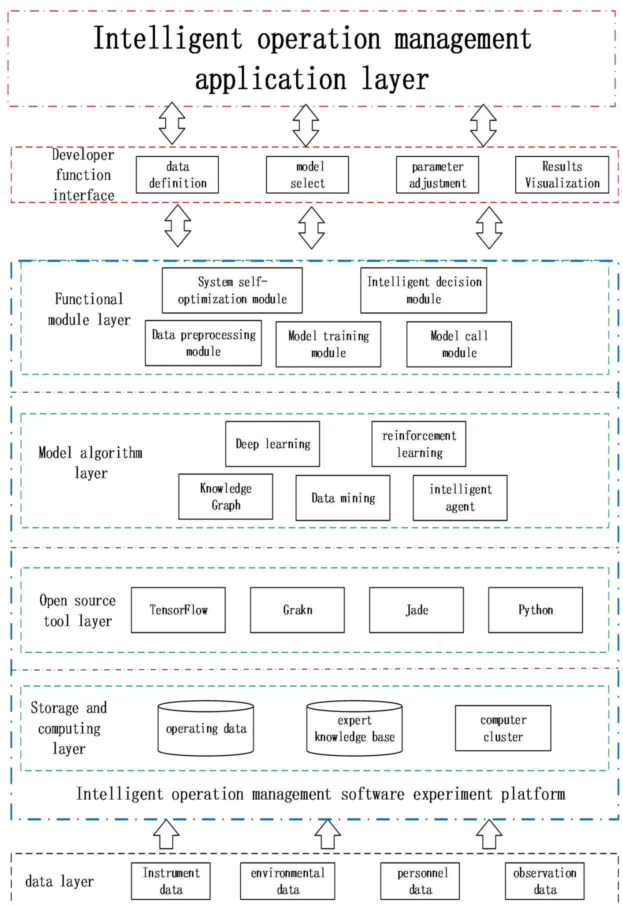

Figure1 Intelligent operation management software experiment platform

(1) the data layer

The data layer is mainly composed of device data, environmental data, personnel data and observation data. Device data refers to the design and manufacturing parameters and operation status data of the telescope device. Environmental data refers to the data of external influence received by the sensor during the operation of the telescope. Personnel data mainly refers to the work scope, professional skills and work experience records of the professionals operating and maintaining the telescope. Observation data refers to the observation plan and observation result data.

(2) Storage and computing layer

The telescope generated a great deal of data. This project intends to design a cluster of computers to provide distributed storage and computing power.

(3) Open source tool layer

This project intends to use Tensorflow, Grakn and Jade to model the prototype, and Python is used as the main development language.

(4) Model algorithm layer

This project intends to build the experimental platform by combining advanced artificial intelligence methods, including knowledge mapping, data mining, deep learning, reinforcement learning, intelligent agent and other cutting-edge technologies.

(5) Function module layer

This project intends to establish a meta-service which is composed of five functional modules to support the development of higher-level services and reduce the development cost.

· Data preprocessing module: The input data set is cleaned, normalized and revamped to reduce the impact of abnormal data, missing data and unbalanced data on the prediction results. Finally, the data set is divided into training sets, verification sets and test sets.

· training module: A collection of advanced deep learning models can be customized for user needs. The preprocessed data was input into the customized model for training. After continuous iterative training, the model will meet the requirements.

· invocation module: The trained model can be loaded and then accessed to the real-time data source to obtain the output result of the model.

· Intelligent decision module: By using intelligent agent, reinforcement learning, deep learning and other technical analysis models, combining with empirical rules, maximum incentive mechanism and other ways to optimize the overall system solution. Finally, get the output of the solution.

· System self-optimization module:

(6) Developer functional interface

Through this functional interface, developers can define data properties, select the model, adjust the model's super parameters and so on.

(7) Intelligent application layer of control system

The telescope has a variety of different functional requirements in the control system. According to each requirement, the meta service is called to develop and design various application software.

3. OPERATION RELIABILITY MANAGEMENT

Establish a prediction model for the operating life of key components of large astronomical telescope. A maintenance plan will be made based on the model, and an emergency management plan will be established.

(1) This project will establish a model for predicting the operating life of key components of large astronomical instruments.

This project intends to adopt AI method to analyze the fatigue life of key devices, predict the failure probability and average failure time of devices, and provide reference for the maintenance scheme of astronomical instruments. The life model of the device is studied mainly from two aspects of internal characteristics and external conditions. Internal characteristics include static characteristics, such as device structure, vendor, etc. Dynamic characteristics include running time, operating environment, interaction between devices, etc. External conditions include environmental external conditions, operating internal conditions and so on. The operation of the device is affected by environmental factors. Unstable external environment will bring sudden failure to the device maintenance work. The occasional failure during the lifetime may cause the interruption of observation and bring unnecessary loss and difficulty.

(2) This project intends to adopt AI methods to assist the decision of maintenance plan.

The research on the life prediction of the key components of astronomical instruments is to judge the life of the components, predict the failure trend of the components. It provides the decision basis for the maintenance and update of the key components of astronomical instruments. The research evaluates the operating state of the components which can effectively guarantee the normal operation of the system.

At present, the maintenance decision of large astronomical instruments is usually divided into long-term periodic maintenance and short-term routine inspection. For example, LAMOST will focus on the observation dormancy time in summer to carry out comprehensive maintenance inspection, and carry out routine inspection and emergency maintenance tasks for occasional faults in the observation season. The maintenance plan is not scientific, accurate, systematic and perfect.

Based on the prediction of the life model, the optimal maintenance scheme is determined by comprehensively considering the time window, cost, priority and other factors. The scheme is aimed at minimizing the average maintenance cost of astronomical instruments and maximizing the available observation time.

(3) Make emergency management and plan through big data comprehensive analysis and intelligent decision

The maintenance and operation of astronomical instruments should consider sudden catastrophic accidents. Informatization and intelligent analysis is the key problem of early warning and early disposal for the sudden and catastrophic accidents. Sudden catastrophic accidents are usually caused by factors such as device fatigue and environmental change. AI provides a rare opportunity for scientific and precise emergency management. It can organically collect and integrate various internal and external data, propose emergency strategy, rules and regulations and emergency plan through intelligent decision support, and improve emergency management ability. Research on the life prediction, maintenance decision and emergency management of the key components of astronomical instruments is of great significance for improving the reliability and safety of astronomical instruments.

4. OPTIMIZATION OF OBSERVATION QUALITY

The difference of temperature near the telescope (especially the primary and secondary mirrors), and the difference of temperature between the environment outside and the dome is the main cause of the dome seeing. This is a problem with almost every large astronomical optical telescope.

Currently, cooling, ventilation, opening the shutters and equipping with heat shields are the main methods to improve seeing. Take LAMOST as an example. There is basically a fixed operation process of opening dome, cooling, ventilation and so on every day. These processes often don't take into account actual weather conditions and changes of the temperature inside the dome. There is also no theoretical basis for when and what steps to take.

Temperature gradients of the entire dome can be constructed by installing temperature sensors in the optical path and at various locations.The AI method is adopted to comprehensively consider the influence of the environment inside and outside the dome on the dome's seeing, and the optimization strategy of the dome's seeing is given in order to propose a solution for the dynamic improvement of the dome's seeing.

The main controlling factors affecting the seeing inside the dome are the heat source near the telescope which are mainly caused by the temperature difference between the doom inside and outside. Therefore, the modeling is carried out for the indoor and outdoor temperature difference and the related factors which affect the temperature difference. The process is as follows:

(1) Data preprocessing

Collecting data which affects the dome seeing such as indoor and outdoor temperature, temperature of the main heating parts of the instrument, operating status of the instrument, weather and other data. These data was carried out through cleaning, redundancy removal, normalization, data amplification and other operations.

(2) Construction and training of seeing model

The seeing data, indoor and outdoor temperature difference, and the operating state of the instrument are all continuously time series data. A time series model based on deep learning can be established to predict the seeing in the next state. The preprocessing data was input into the model, and the parameters between the network layers were recursively adjusted by the gradient descent method, so as to fit the model with the highest prediction accuracy.

(3) The invocation of the seeing model

Real-time data such as indoor and outdoor temperature, operating state of the instrument and weather data are input into the trained seeing model to obtain the seeing result.

(4) Decision stage

According to the rule of the seeing plan, make the possible decision action strategy.

5. CONCLUSION

This project intends to study how to combine the advantages of deep learning and knowledge mapping. The research results of this project will provide technical support for the automation of the control system to the intellectualization of the control system for the existing telescopes. This research team has accumulated a lot of work experience and historical data on LAMOST, which has laid a solid foundation for this project. The objective of the research results will provide the existing telescopes from automation control system to intelligent control system, and for the next generation of Chinese large astronomical optical telescopes (such as 12 meters optical telescope LOT), and the design of the operation can also promote other subjects related to intelligent development of large, complex instruments.

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